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Principles of Color Sensitometry

A Report of the Color Sensitometry Subcommittee

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C. F. J. Overhage, *Editor*

Contents

Submitted: March 15, 1950, to the Chairman of the Color Committee

SOCIETY OF MOTION PICTURE AND TELEVISION ENGINEERS

Foreword

IT WAS THE CONSENSUS of the members of the Color Committee that a report outlining the principles of color sensitometry would be one of the most urgently needed contributions the Color Committee could make to the membership of this Society and to the industry as a whole.

A Subcommittee was organized in March, 1949, with that objective in mind. They undertook the preparation of a report that would review the functions of color sensitometry, the fundamental concepts involved, their approximate realization in practical use and with available instruments, and the areas in which further research is necessary before definite procedures can be recommended for general adoption.

It was recognized that a rather difficult and insufficiently developed subject had to be presented. It is a matter of great satisfaction to report that invitations to serve on the Subcommittee were accepted promptly and assignments carried out with unusual promptness considering the highly technical and frequently controversial nature of the work. From its beginning, the project has enjoyed excellent support from all quarters in the motion picture industry.

The Subcommittee has stressed the fact that the present understanding of the fundamental principles of color sensitometry is incomplete. Further research is necessary to establish the theoretical foundations of color sensitometry and a great deal of industrial experience is required to evaluate the practical merits of the procedures discussed in this report. However, it is believed that the initial objectives of the Committee have been adequately covered.

It is to be hoped that the technical knowledge and guidance provided by the report will be helpful to the industry and that it also will have the effect of directing industrial practices into channels so that in years to come standardization of the more important aspects of color sensitometry can be undertaken with a greater expectation of unanimity of acceptance than would otherwise be possible in this complex field.

The report of the Subcommittee appears as a uniform, anonymous presentation, reflecting the views of all members. The editing was done by the Chairman, C. F. J. Overhage, who acknowledges the valuable assistance of his associates: A. M. Koerner, R. H. Morris, G. Wernimont in the preparation of Sections III and VIII, and F. C. Williams in the final review of the entire report. Special credit should be given to those members of the Subcommittee who prepared the first complete drafts of the other Sections: L. E. Clark (Section V), A. M. Gundelfinger (Section VI), M. H. Sweet (Section VII), J. P. Weiss (Section II), and F. C. Williams (Sections I and IV). The efforts of the West Coast members of the Subcommittee were effectively co-ordinated by J. G. Frayne.

The Chairman of the Color Committee wishes to express his appreciation to the members of the Subcommittee for their enthusiastic support of the program. Special recognition is due Mr. Overhage who has been the driving force behind the project.

HERMAN H. DUERR, *Chairman*
SMPTE Color Committee

I. INTRODUCTION

Color photography is an exacting endeavor. When we see a beautiful and apparently accurate color reproduction on a motion picture screen, we see the product of a long train of precision work. It is work with little tolerance of trial and error; errors can run in too many directions and can appear in too many places to be discovered and overtaken by trial. Economical practice of color photography affords little room for operation by guess or even by estimate. It demands operation by measurement. This measurement must result in quantitative knowledge of the character of the materials in use, of the effects of laboratory handling, and of the nature of the photographic images formed—knowledge sufficiently accurate and comprehensive to insure efficient production of best possible results. The science which specifies most of these measurements, and the ways of making them, is photographic sensitometry.

Although the principal concern of photographic sensitometry is the determination of quantitative relationships between photographic exposures and the images they produce, it deals with the entire photographic process from subject to observer. It examines exposures and specifies the kind and amount of radiant energy which the film should or does receive. It tests and helps control the sequences of chemical treatments which form in the exposed material the visible photographic results. It measures the processed images, determining their character or contents in terms most useful for the product's application or most significant in an operation's adjustment or stabilization. Finally, it determines the reactions of observers and relates their quality judgments to physical characteristics of the photographic material. It does these things by employment of techniques and tools which are specialized for the job, and it expresses results in special units and language designed for the purpose.

Color photography has brought into sensitometry new methods, new instruments, and new terms tailored to the new task. They contribute to a new division of the science called *color sensitometry*. Much of color sensitometry is built on basic principles familiar in sensitometry of black-and-white materials. Some principles are new. It is the object of this report to outline these principles and to describe the methods and instruments of color sensitometry in order to give to workers in the field of color motion picture photography a comprehensive view of the present state of the science as it applies to them.

The treatment is not detailed, and in some places rigor has given way for better understanding, but the coverage is intended to be comprehensive.

Color sensitometry is used in the motion picture industry in two broad fields of application: in the *evaluation* of techniques and materials, and in their *control*. As a tool of evaluation it is meant to provide straightforward objective descriptions of color film images and indirectly therefore of the characteristics of a film, or a processing operation, or a printing system. It provides a language in which quality and performance can be discussed. These objective descriptions are especially valuable for comparing photographic films with an ideal, with a practical aim point, with a tolerance limit, or with an alternative product.

Other sensitometric measurements are required in control operations, especially where control is exercised by application of corrective measures to minimize unwanted variations. The manufacturer requires such control to keep his product uniform. The processing laboratory may require it to produce repeatedly the same result from successive processings of identical material.

There is, naturally, wide variety in the procedures used in the diverse applications of sensitometric methods; yet one basic routine is common to nearly all tests: Exposures are imposed on a sample of film, the sample is processed, the resulting images are measured by some densitometric technique, and the data from these measurements are arranged in a form suitable for the required interpretation which follows. The present report takes up these procedures individually, in the order of that routine. For each step, there is discussion of the fundamental concepts involved, and of their embodiment in practical procedures suitable to the motion picture field.

This report is intended to apply primarily to subtractive processes—those in which color variation in the image is achieved by varying the amounts of superimposed dye images, each of which can substract from the incident energy chiefly light of one color. Most of the methods have been developed for use with three-component multilayer subtractive films—those which form cyan, magenta, and yellow dye images in three separate sensitized layers, all on the same transparent support. Many of the basic principles, and some of the specific methods, are also applicable to other color film types. No consideration has been given to color materials with opaque supports such as color-print papers.

II. SENSITOMETRIC EXPOSURES

The basic procedure in color sensitometry begins with the exposure of the test sample. Because of the wide dissimilarity in characteristics and application among various color films, a general discussion of sensitometric exposures must necessarily deal with basic principles rather than specific details. The color products now on the market include taking stocks, print stocks and intermediates. Some color taking films are processed as negatives, others by reversal. Certain print stocks are designed to be printed from separation negatives and some from a colored negative or positive. Each basic type requires a different sensitometric treatment because of its unique characteristics and method of use.

The chief guiding principle is that the sensitometric exposures should duplicate as closely as possible the conditions of actual use. The importance of this has been demonstrated time after time in black-and-white sensitometry, and it is even more pertinent in color. The complexity of color films is much greater than that of black-and-white materials and the tolerances under which a color system operates are closer.

Time vs. Intensity Variation*

In the choice between sensitometers involving a variation of exposure time with constant intensity, and those in which the exposure time is kept constant and the intensity varied over different areas of the films, (time-scale vs. intensity-scale), the principle of simulating conditions of use favors the latter type by an almost overwhelming margin. Because of reciprocity law failure[1] a time-scale more than likely will not give the same result as the intensity-scale involved in actual use. The seriousness of the disagreement will of course depend on the characteristics of the particular film.

In black-and-white photography it has been a fairly widespread practice to use time-scale sensitometric exposures for process control, where it is wished to check reproducibility of development. Sensitometric values are measured on the processed strips and correlated

* In the classical papers of Abney and of Hurter and Driffield, photographic exposure was referred to as the product of "intensity" and time, and this use of the word "intensity" has continued in photography, although it means something else to physicists and illuminating engineers. The Colorimetry Committee of the Optical Society of America has proposed *irradiance* to designate the radiant power incident on unit area of a receiving surface, and *illuminance* for the corresponding luminous power. Pending a general clarification of photometric terms, this report will follow current trade practice in speaking of *intensity*.

with actual pictures. The values associated with optimum picture results are selected as reference values. Once this selection has been made, it is assumed that photographic performance will be maintained at optimum level if the development is always so adjusted that the sensitometric values obtained on processed time-scale test strips remain the same as the reference values. This procedure is fairly reliable as long as the reciprocity characteristics of the film remain constant from batch to batch, and the development conditions (such as developer composition) do not vary too widely. Such assumptions have been found not always valid in black-and-white, and they are much more risky in color. Since the three emulsions of a typical color film are not usually identical in formulation they may well be expected to have reciprocity law characteristics which vary differently as film conditions or development vary. Because the development conditions for the three layers are necessarily different, the influence on reciprocity characteristics of development changes will differ among the three layers. Thus, even for development control, test strips with time-scale exposures are lacking in reliability.

Step Wedges

The ideal device for producing a variable intensity exposure on film would be accurate, reproducible from specification, and would not change the spectral quality of the radiation as it varied the quantity (i.e., would be nonselective). To vary exposure by increasing the distance of the source according to the inverse-square law is technically a perfect solution, but unfortunately results in a sensitometer too enormous and cumbersome to be practical. Optical systems which come very close to meeting the ideal requirements have been described,[2,3] but these have the drawback of being quite complicated and expensive. The step wedge remains the most practical compromise between convenience and economy vs. technical perfection. Both photographic and colloidal graphite wedges which are quite satisfactory for practical sensitometry are commercially available.

While run-of-the-mill step wedges do not qualify for highest accuracy, selected wedges may be found which have quite uniform and accurate steps. The greater the accuracy required the higher the cost of manufacture, so that a top quality wedge is not cheap. For most purposes, such as processing control, highest accuracy is not needed. Again, wedges can be calibrated individually for more accurate data.

The absorption of radiation in its passage through a step wedge

should be the same for all wavelengths. If this is not the case, the step wedge is rather unsatisfactory for color sensitometry. In testing multilayer color film, each emulsion is exposed to only a small portion of the spectrum. A slight yellowish tint which could be ignored in black-and-white sensitometry will cause the wedge densities to be quite different for blue light, say, than for red. In general, photographic wedges are better in this respect than those made of colloidal graphite and thus may be preferred despite the greater accuracy and durability of the latter. The graphite wedges have such significant variation of density with wavelength that for accurate work a separate density calibration is needed for each spectral region. Such calibration is best performed by a system similar to the American standard method for determining contact printing density.[4]

Wedges with 0.15 density increment ($\sqrt{2}$ factor) per step are quite satisfactory for color films. Those with 0.30 density change per step might serve for low contrast negative films, but such steps are entirely too coarse for accurate evaluation of color positive stocks, which ordinarily have quite high contrast. Preferably the wedge should have a density range of from nearly zero to 3.0. A lesser range will sometimes be acceptable because color film does not ordinarily reproduce a very wide subject brightness range.

The geometrical dimensions of each step must be chosen within limits imposed by practical considerations. The cost of test film and the difficulty of providing uniform intensity over a large field prohibit the use of very large areas. On the other hand, a very small area may give misleading results because of adjacency effects[5] and make excessive demands on the sensitivity of densitometers. A step width of 0.4 in. is widely used and appears to be a satisfactory compromise. In a conventional test exposure, the other dimension of each step is at least equal, and may extend across the entire width of the film. Where automatic recording densitometers are to be used, it may be desirable to have a sensitometric strip which varies continuously in density rather than stepwise. This can be achieved by using a wedge with a continuous and uniform density gradient.

Exposure Times and Intensity Levels

To avoid very confusing inaccuracies caused by reciprocity law failure, it is of greatest importance to select an exposure time for a color sensitometer which will be nearly the same as in the camera or printer which actually uses the film. $\frac{1}{50}$ sec is probably close to an

average motion picture camera exposure time. In intermittent printers the exposure is apt to be somewhat slower, say $\frac{1}{10}$ to $\frac{1}{20}$ sec, but there is great variation among different machines. Again, the exposure should be applied in a single flash, not an intermittent series of shorter exposures. Obviously an accurate shutter such as a rotating sector disk or drum must be provided, for correct exposures of such duration cannot be achieved by turning the light source on and off.

Once the characteristics of the step wedge are established and the exposure duration selected, the intensity level must be adjusted accordingly, so as to produce exposures at least as great as the maximum given to negatives or prints in use. In designing a sensitometer for color taking films, obtaining sufficient light is not likely to be a serious problem for films used with artificial illumination. If the sample to be exposed is, for example, a 10-in. strip of film fast enough for camera use, then a 500-w lamp will have ample output, and will give even illumination at a distance of about a meter.

Providing enough light to expose a daylight taking film or a color *print* film, on the other hand, may call for unusual sensitometer design. The production of artificial daylight by suitable filtering of radiation from an incandescent source requires rather dense filters. The resulting intensity is therefore low. To match the intensity levels of daylight exposures in cameras with fast lenses requires a 500-w source about 6 in. from the film. Print stocks are inherently slower, and are usually exposed through fairly dense band-pass filters.

One approach toward providing enough light in these cases is to use a short wedge with narrow steps, so the lamp-film distance may be made smaller, still achieving uniform illumination. A second way is to expose only one or two steps at a time, stepping the wedge and film along between exposures of individual steps. Thus the area to be illuminated is very small and the lamp may be extremely close. A variation of this design is to move the wedge and film with uniform velocity past a narrow exposing slit. This eliminates the need of a separate exposure-timing shutter. One such sensitometer has been described by Sweet.[6] Care must be taken to achieve very smooth, uniform motion of the wedge-film carriage, otherwise a striated exposure will result.

Selective Exposures of Individual Layers

The exposure methods most frequently used at present in the testing of color film are (a) to expose the emulsion layer selectively to pro-

duce the individual subtractive colors separately, or (b) to expose them in combination to obtain a gray scale, or both. Actually, each procedure yields some information which the other does not. Making the exposures separately permits simplification of the densitometry of the images, and detection of the presence of any degradation of the primary images caused by migration of color-formers or print-through effects. On the other hand, the image formed in an emulsion layer as a result of a selective exposure which affects only one emulsion layer is somewhat different from the image which would be formed in that emulsion from an exposure which also affects adjacent emulsion layers. This difference is a consequence of inter-layer development effects which may have considerable practical influence on color reproduction. Therefore, complete sensitometric testing of color film should include nonselective gray scale exposures as well as selective exposures of individual layers.

Means of making both types of exposure are discussed under the next heading.

Spectral Quality of Radiation

When making sensitometric tests of a color taking stock, it certainly will be desired to include an exposure to light of the same quality as that which the film receives in the images of white objects under the illumination for which it was designed, e.g., daylight, or 3200 K tungsten. In a reversal film especially, it is important to check that the three emulsion layers are balanced for speed as well as contrast in a gray scale exposure. If the film is balanced for daylight, the sensitometer should be equipped with a combination of light source and conversion filter which will produce simulated daylight. The Davis–Gibson liquid filters[7] give the most nearly accurate conversion, but have some drawbacks for routine use, being prone to leak after a time. The Corning Series 5900 are probably the next best and are permanent and convenient to use. Unfortunately, such combinations, while giving a pretty good visual match, are not a perfect spectral match for true daylight; therefore, the relative speeds of the three layers as determined from the artificial daylight exposure will not be exactly those which would be determined from exposure to natural daylight. The search for better conversion filters continues: Bingham[32] has discussed the design of a filter consisting of two colored glasses between which is cemented a gelatin layer containing four dyes. However, it must be borne in mind that natural daylight itself varies a great

deal in its spectral composition, and that at best a source-filter combination can only simulate a single condition (for example, one of the five phases of daylight described by Taylor and Kerr[33]). Finally, it must be pointed out that the filter problems become less severe as the color temperature of the primary light source is increased. Sensitometer lamps used with conversion filters should, therefore, be operated at the highest color temperature consistent with acceptable stability and lamp life.

Filters with fairly narrow spectral transmission bands are required to expose the individual emulsion layers selectively. The choice of peak wavelength and band width will be dictated by the position of film sensitivity peaks and the degree of overlap in the sensitivity of the three layers. In some color films the sensitivities may overlap so much as to make it impossible to confine a full-scale sensitometer exposure to a single layer with any filter. The film manufacturers will be able to recommend the most appropriate filters for their products. In the case of color print films these may be the same filters as recommended for printing from separation negatives.

Exposures for Sound Track Control

Sensitometric exposures for sound track control of a print film will be quite similar to those used for picture control. Some differences in exposure times and printing filters may be encountered, and the sensitometry must be modified accordingly to simulate use more closely if these differences are large enough. In particular, the filter used for printing the sound track may not confine the image to a single emulsion layer, in which case it will be especially important to follow actual practice.

In some color films the processing of the sound track area includes special treatments (e.g., the conversion of positive silver halide to silver sulfide) that are not applied to the picture area. When this is the case, sensitometric exposures must be similarly treated. This may require placing the test exposure on the film in the sound track location so that it will go through the track-treating device.

When color taking stocks are used for sound recording in single-system cameras, the track exposure time becomes substantially different from the picture exposure. For rigorously accurate sensitometry, the exposure time for the sound track test should follow suit, which calls for quite radical sensitometer design, as has been described by White.[8]

III. THE PROCESSING OF SENSITOMETRIC TESTS

The image which results from the processing of a controlled sensitometric exposure is determined by two factors: (a) the characteristics of the particular piece of film on which the exposure was made, and (b) the characteristics of the process through which the film passed. Normally, both sets of characteristics change with time. If one of these factors can be held constant, sensitometric images can be used as controls for the other factor. This has been attempted in two ways:

(1) To study variations between different samples or different coatings of the same type of film, sensitometric exposures are handled on a "sensitometric process" that is considered constant and free of the day-to-day changes and gradual drifts of the normal production process.

(2) To study variations between different performances of the same process (different machines, different processing stations, or different days on the same machine), sensitometric exposures are made on a reference emulsion ("check" or "type" emulsion) that is considered uniform throughout, and free of the gradual variations that normally occur with the passage of time.

Sensitometric Processes

If one is interested in determining the characteristics of a film sample, as is the case when sensitometric exposures are used for purposes of manufacturing control, or of evaluating deliberate changes in the product, or of determining the effect on the film of pre- and post-exposure storage conditions, then the characteristics of the process through which the film is passed must be known to a degree of accuracy which is commensurate with the accuracy to which it is desired to determine the film characteristics. This calls for rigorous control of the variables which occur in the chemical composition of the solutions, solution temperatures, agitation, etc.

It is usually felt that these factors are not sufficiently well controlled in processes used for production purposes to guarantee an adequate evaluation of the film characteristics. For this reason, so-called sensitometric processes are often set up for the purpose of determining film characteristics. These sensitometric processes differ from production processes in several ways.

In the first place, sensitometric processing machines are smaller and capable of handling only a limited amount of work. The small size of the machine permits the use of small volumes of processing solutions. Because of their small volumes, these solutions can economically be discarded after each processing so that the danger of lack of control through solution deterioration is minimized. Furthermore, because of the small volumes involved, individual batches of the dry chemicals used in making tank solutions will last a long time, whereas in the production processes frequent changes from batch to batch are required. Thus the danger of lack of control arising because of variations between batches of chemicals is also minimized. For weighing the small amounts of chemicals involved in the sensitometric process, more precise equipment can be employed. In mixing, greater care can be taken to avoid excessive stirring in of air. The timing and temperatures of mixing can be rigorously duplicated. In general, the whole operation of setting up chemical solutions can be conducted on a laboratory rather than on a production basis, and higher precision can be expected in the extent to which processing solutions meet specifications.

Furthermore, in the sensitometric machine an effort is made to specify and control the degree of agitation more accurately. In one type of machine,[9] agitation is produced by a set of vanes, which move up and down or across the tank. These vanes can be set and maintained at specified angles to the plane of the film, and their speed of movement and number of trips back and forth can be accurately controlled. The temperature of the processing solutions can also be more precisely held at a predetermined figure.

Thus it should be possible in a sensitometric process to control much more closely each of the physical and chemical characteristics of the process.

Chemical Control

An important adjunct to the maintenance of a sensitometric process is the use of chemical analyses. These are of primary importance in checking the uniformity of the dry chemicals and in making up the processing solutions. It is often assumed that sufficient uniformity from batch to batch is assured by the manufacturer's tests prior to shipment, but it must be remembered that the manufacturer's checks may not be designed to test the chemical under the particular conditions of use to which it is put in the customer's process. The most

effective safeguard, therefore, is to set aside special batches of chemicals for use in the sensitometric process, and to conduct special comparison tests when it becomes necessary to change to a new batch.

Chemical analyses are also available to check the concentration of each of the important constituents in processing solutions. While this is one of the major control methods in production processes,[34] its use in sensitometric processes is limited by the fact that chemicals can be weighed out and mixed with greater accuracy and precision than that with which chemical analyses can be made. The method therefore provides insurance only against gross errors in mixing. The performance of the analyses is also an expensive operation involving the use of specialized personnel and equipment. For these reasons, sensitometric processing machine solutions are rarely analyzed.

Comparison with Production Processes

In setting up a sensitometric process for the purpose of checking film characteristics, it is a fairly obvious requirement that the sensitometric process must closely match the production process through which the film in question is normally used. This match should exist not only for the over-all process but also for each step in the process. Hence sensitometric processes are usually set up progressively, by stages, each of which must yield a photographic result which matches that from the corresponding stage in the production process.

The procedure of establishing the sensitometric process usually starts from the assumption that chemically the processing solutions used must be identical with the seasoned solutions in the production machine. Any adjustments that are necessary to give the same photographic results will be made in the physical factors and not in the chemical phases. It is usually considered desirable that the two machines should also be matched with respect to the temperatures of the processing solutions, and with respect to the time the film is in each step of the processing sequence and each passage between successive solutions. The principal controls available to create a match in the photographic results are, therefore, the mechanical adjustments which vary the agitation of the solutions in the sensitometric machine. When these controls are insufficient, minor changes in solution composition are resorted to. It is often true that even under the best of conditions an exact match cannot be obtained between the two machines. Under these circumstances the sensitometric machine will

still be found to be a useful tool, but the discrepancy from production results must always be borne in mind.

Check Emulsions

The problem considered thus far has been the use of sensitometric exposures for the purpose of determining film characteristics. If one is interested in the determination of processing characteristics, for example in studying the day-to-day behavior of a production machine, sensitometric exposures will again be used, but it is now essential that film variations are not superimposed on the process variations which are to be detected. This requires the use of a check emulsion.

The check emulsion is simply a uniform batch of film of a type similar to that which is normally handled in the process under discussion. Such a batch is selected after making repeated processings of sensitometrically exposed samples and determining, from the average of these results, the photographic characteristics to be expected on this film. The extent to which the results on any subsequent processing of a sample of this film agree with the above average is taken as a measure of the degree to which the process is in control.

The use of a check emulsion for the determination of processing variations rests on the assumption that its pre-processing characteristics do not change in time and are uniform throughout the coating. This is not completely valid for any actual film, and several precautions must be taken to keep the departures from the ideal state sufficiently small to prevent serious errors.

(1) Photographic films are not stable in their exposed or unexposed states. Although film stability is increased by storage at low temperatures, no practical conditions are known at which complete stability can be assured. Thus it cannot be assumed that the check emulsion will remain constant indefinitely.

(2) The effect of the exposure on the film does not remain constant for long periods of time prior to processing. Latent image growth or decay occurs. Thus the time consumed between exposure and processing, as well as storage conditions during this interval, if it is appreciable, must be carefully controlled.

(3) No large batch of film is completely homogeneous; variations occur within the area of a coating. For precise work, it must be recognized that such variations may exist in the check emulsion. They can be evaluated and discounted, however, by using for each

test a number of properly randomized samples of the check emulsion coating.

Aside from errors caused by variations in the check emulsion, there is a fundamental hazard in this method of process control. The process may not be actually in control even when sensitometric tests on check emulsion samples yield normal results. Such a situation may arise when one off-standard condition in the process (say in agitation) has been counteracted, so far as its effect on the check emulsion is concerned, by a second off-standard condition (say in temperature). Although the effects of these two off-standard conditions counteract each other in the check emulsion, it cannot be assumed that they will always similarly counteract each other in other emulsions which are to be handled in the same process. The danger of errors of this type can be minimized by supplementing the sensitometric tests with other control methods, such as determinations of temperatures, flow rates, and chemical concentrations.

Process Control

The preceding sections have outlined the principles which govern the processing of color sensitometric exposures. The ultimate goal, as in all test techniques, is to hold one group of variables constant while studying the changes in another. It will be clear from what has been said that only an approximation to this ideal state can be achieved. Sensitometric processes are not perfectly repeatable, nor are check emulsions perfectly stable. Individual sensitometric results will always be somewhat influenced by secondary variations in factors that should, in principle, be constant. The combination of many individual results by statistical methods and their interpretation by previous experience constitute the precarious art of process control, for which color sensitometry is merely one of the basic tools.

Table I. Descriptions of Color Density Types

Color densities can be divided according to geometrical properties of the densitometer:

Specular Densities. The incident light is collimated; the receiver has a very small aperture accepting only undeviated light.

Diffuse Densities. (a) The incident light is nearly collimated; the receiver accepts all transmitted light, or (b) The incident light is diffuse; the receiver has a small aperture. *Page 670.*

Color densities can be divided according to purpose:

Integral Densities. The effects of image absorptions are expressed in terms of decrease of response of some kind of receiver in an optical system. *Page 669.*

Analytical Densities. Composition of the image is stated as amounts of component absorbers (e.g., cyan, magenta, and yellow dye deposits). *Page 678.*

Integral densities can be divided according to the kind of response that is controlled by the image, or the kind of receiver in which that response is generated. For measuring each type of density, the densitometer must provide the corresponding spectral weighting of the image transmittances:

Printing Densities. In normal film use (printing), the receiver is a print material; the response is latent image formation. In a densitometer, the receiver is usually a photocell in combination with suitable filters. *Page 671.*

Colorimetric Densities. In normal film use (viewing), the receiver is the mechanism of vision; the responses are the component colorimetric responses of a standard observer (e.g., the 1931 ICI observer). In a densitometer, the receiver is usually a photocell in combination with suitable filters. *Page 674.*

Luminous Densities. In normal film use (viewing), the receiver is the mechanism of vision; the response is the luminosity response of a standard observer (e.g., the 1931 ICI observer). In a densitometer, the receiver is usually a photocell in combination with suitable filters, or the visual mechanism itself. *Page 675.*

Arbitrary Three-Filter Densities. These densities do not correspond to a specific film use. In a densitometer, the receiver may be the visual mechanism or a photocell; the response is whatever the receiver gives in the employed optical system, usually using arbitrary red, green and blue filters. *Page 675.*

Spectral Densities. These densities are important for fundamental description rather than the direct representation of a specific film use. In a densitometer, the receiver may be any detector of radiant energy of a narrow wavelength interval—ideally a single wavelength. *Page 677.*

Analytical densities can be divided according to the kind of component which is assumed to make up the image, and the scale on which the amount of that component is expressed:

Spectral Analytical Densities. The assumed components are usually the dye deposits of the color process; the amount of dye is expressed as its spectral density at some one wavelength. *Page 678.*

Equivalent Neutral Densities. The assumed components are usually the dye deposits of the color process; the amount of dye is expressed as the luminous density of the gray image which could be formed by adding to the single-dye deposit under consideration sufficient quantities of the other dyes of the color process. *Page 680.*

Equivalent Neutral Printing Densities. The assumed components are usually the dye deposits of the color process; the amount of dye is expressed as the printing density of the image which could be formed by adding to the single-dye deposit under consideration sufficient quantities of the other dyes of the color process to form an image with red, green and blue printing densities all equal. *Page 682.*

IV. QUANTITATIVE EVALUATION OF THE IMAGE*

Sensitometric tests emerge from the processing operation in the form of processed film samples. These samples usually contain test scales, which are sets of small, uniformly colored areas which have received precisely controlled exposures. Each of these areas may be regarded as a color filter, with absorption characteristics determined by the exposure and processing it received and the characteristics of the film which the test sample represents. The sensitometrist desires certain information about the exposure, the processing, or the film characteristics. He obtains it by measuring the light absorption characteristics of the test areas.

The kind of measurement used depends on the kind of information wanted. Measurements called *integral densitometry*[16] are used to determine the effects which the absorptions of the image will have on some action of the light beam which it attenuates, such as on the printing of a positive material or on the stimulation of an eye. Measurements called *analytical densitometry*[14] are used to determine the composition of the image in terms of amounts of its component absorbers, such as the amounts of yellow, magenta, and cyan dye which together may form an image.

Integral Color Densitometry

Any color transparency produced by a motion picture laboratory will be used, if at all, in some kind of optical system. Integral color densitometry, therefore, must determine the effect of the transparency, when inserted in the optical system, on whatever response the system is intended to generate. The systems of principal interest in the motion picture field are photographic printers (contact and projection) and projectors. They are examples of the larger classes, printing and viewing systems. The response generated in a printing system is a photographic response—the formation of latent image in a print material. Densities which describe the action of transparencies in decreasing this response are *printing densities.*[10] The response generated in a viewing system is a visual response—the stimulation of color receptors in the visual mechanism. Densities which describe the action of transparencies in decreasing this response are *colorimetric densities.*[14]

* *Note:* A summary of the terms introduced in this section to describe different types of density is given in Table I, on the page opposite.

The effect of a transparency (by which is meant here and henceforth a uniformly colored area of processed film) on either a photographic response or a visual response can be determined quantitatively by actual use of the photographic material or the visual mechanism, but the procedures are difficult and slow. For routine operations an instrument—a *densitometer*—is used in which the response of a photoelectric cell or other receiver replaces the photographic or visual response. In either case the absorptions of the transparency reduce the power of the incident light to produce the response. The function of the densitometer is the exact determination of the reduction of the response caused by the film in a given practical application.

Effects of Scattering

Transparencies scatter light as well as absorb it. A densitometer which correctly evaluates the transparency's action must correctly evaluate the effects of this scattering. This would seem to require for each projector system or printer system a densitometer with an optical system essentially duplicating that of the projector or printer. Actually, this is not required. Color transparencies which scatter appreciably usually confine most of the scattered radiation to a cone of very small apex angle, centered on the undeviated ray. The apertures of practical optical systems are large enough to accept the entire cone, except for marginal rays. The aperture of the densitometer must be at least large enough also to accept the cone of principal scattering. If the aperture is larger than this cone, only small errors will be incurred. If *all* the light transmitted by the transparency—scattered and unscattered—is accepted by the densitometer optical system, its density evaluation will still be satisfactory for most purposes. Such instruments are said to measure *diffuse density*. They are generally accepted as best for standardization to insure agreement among several instruments.

Spectrum Weighting

Correct evaluation of the transparency's absorption requires careful treatment. Color transparencies are usually highly selective in their transmission of different portions of the spectrum. The responses which they affect are normally selective with respect to different portions of the spectrum. It is, of course, the interaction of these selectivities that makes color vision and color reproduction possible. It is

obvious that a transparency which looks green should have a lower density to green light than to red or blue light. But its exact density to green light depends on the exact quality of green light used. If a densitometer is to evaluate the spectral transmittances of a transparency in exactly the same manner as they would be evaluated by a print material, the spectral response of the densitometer must meet certain rather rigorous requirements.

Printing Densities

Three factors determine, for any printing system, the power of light of any wavelength, λ, to contribute to the photographic response: (a) the rate, $J(\lambda)$, at which energy of that wavelength is emitted by the printer source; (b) the efficiency, $e(\lambda)$, with which the printer transfers that energy to the print material; and (c) the sensitivity, $S(\lambda)$, of the print material at that wavelength. The photographic effect of the radiant energy of this wavelength, λ, falling on the print material will then be proportional to the product, $J(\lambda) \cdot e(\lambda) \cdot S(\lambda)$. The total photographic effect of all the energy falling on the print material will be the sum of the intensities of the individual wavelengths. Written as an integral, the sum is

$$\int_0^\infty J(\lambda) \cdot e(\lambda) \cdot S(\lambda) \cdot d\lambda.$$

Suppose a transparency is inserted into this optical system, and that at each wavelength, λ, it has a transmittance, $T(\lambda)$. The effect of radiant energy at each wavelength, λ, is now smaller by the factor, $T(\lambda)$. The total photographic effect of all the energy falling on the print material is

$$\int_0^\infty J(\lambda) \cdot e(\lambda) \cdot S(\lambda) \cdot T(\lambda) \cdot d\lambda.$$

The ratio of the second sum to the first is the printing transmittance of the transparency. The common logarithm of the reciprocal of this ratio is the printing density of the transparency, or

$$D_p = \log_{10} \frac{\int_0^\infty J(\lambda) \cdot e(\lambda) \cdot S(\lambda) \cdot d\lambda}{\int_0^\infty J(\lambda) \cdot e(\lambda) \cdot S(\lambda) \cdot T(\lambda) \cdot d\lambda}.$$

A simple densitometer for measuring printing densities may have a source emitting energy at the rate, $J'(\lambda)$, which is transferred with efficiency, $e'(\lambda)$, to a photocell with spectral sensitivity, $S'(\lambda)$. The

density of the transparency as determined by this densitometer will be

$$D'_p = \log_{10} \frac{\int_0^\infty J'(\lambda) \cdot e'(\lambda) \cdot S'(\lambda) \cdot d\lambda}{\int_0^\infty J'(\lambda) \cdot e'(\lambda) \cdot S'(\lambda) \cdot T(\lambda) \cdot d\lambda}.$$

The only condition which will make $D'_p = D_p$ for all possible distributions, $T(\lambda)$, is identical spectral distributions of the products $J(\lambda) \cdot e(\lambda) \cdot S(\lambda)$ and $J'(\lambda) \cdot e'(\lambda) \cdot S'(\lambda)$. Means of accomplishing this condition in practical densitometers are discussed in Section V of this report.

Printing densities are familiar to workers in black-and-white sensitometry.[10] But in black-and-white photography an area of the image has only one printing density in a given photographic system. A color transparency usually has three; either it is printed on three differently (red, green and blue) sensitized materials, or through three dissimilar (red, green and blue) filters. Print-density color densitometers are, therefore, set up to permit rapid shifts among three spectrum-weighting functions, each designed for one of the three $S(\lambda)$ or $e(\lambda)$ distributions. The resulting densities are called *red-printing densities*, *green-printing densities* and *blue-printing densities*. If the three sets of density values of a test scale are plotted against the logarithm of exposure, three characteristic curves result as in Fig. 1. These three curves accurately and adequately describe the printing characteristics of the test scale.

Printing Densities of Other Materials

A densitometer which provides spectrum-weighting functions as described above always reads densities in terms of printing on a *specific* print material, but it will read densities of *any* transparency material. Its use is not confined to the measurement of densities of the negative or positive material which is normally used with that print material. It will measure equally well the printing densities of any other absorber—any negative or positive transparency image, or a silver deposit, or a gelatin filter (disregarding scatter effects). This feature is frequently of considerable value. For example, a printing operation may require reduction of red-printing exposure by a factor of 4, and this is to be done by inserting a red-absorbing filter into the printer optical system. The required filter will have a red-printing density of $\log 4 = 0.60$, as read by the print-density densitometer set

up for the material with which the filter is to be used. Red-absorbing filters invariably absorb green and blue light also; if the effects of these absorptions on the green-printing and blue-printing exposures need be known, printing density measurements also will give this information.

A word of warning is in order, however, in connection with these measurements. It is difficult in practice to adjust the spectrum-weighting functions of a densitometer precisely to the required forms. Approximations are usually necessary. These approximations are chosen to provide minimum errors in the densities of the materials

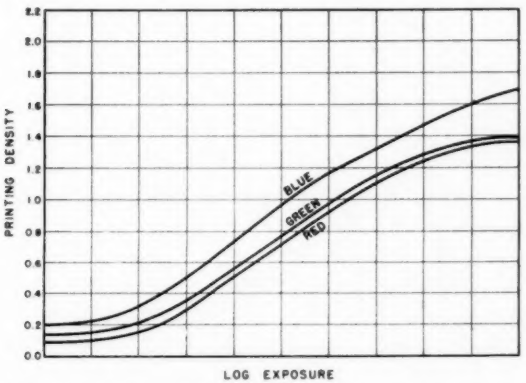

Fig. 1. Printing density plot of the characteristic curves of a typical color negative material. Red-, green-, and blue-printing densities are plotted against the logarithm of exposure. The resulting curves describe the properties of the negative with respect to a specific print material.

usually measured. They may result in appreciable errors in measurement of densities of materials which have spectral transmittance curves different from those of the materials usually measured.

Colorimetric and Luminous Densities

Printing densities are only one kind of integral density. Many color transparencies are not used as intermediate steps of a photographic process, but are intended for direct viewing. Included in this class are direct-reversal amateur motion picture films and release print color films. For these films, measurements of integral image characteristics should determine the effects of the image absorptions

on the visual characteristics of the transmitted light. These are colorimetric measurements.

A unit called *colorimetric density* can be defined and specified in a manner similar to the defintion and specification of printing density. In terms of the trichromatic concept of color vision, the psychophysical color characteristics of light depend on the amounts of three dissimilar responses which it evokes in the visual mechanism. In a colorimetric system each of these responses is assigned a spectral distribution of sensitivity just as each of the three layers of a color print material has a spectral distribution of sensitivity. The spectral dis-

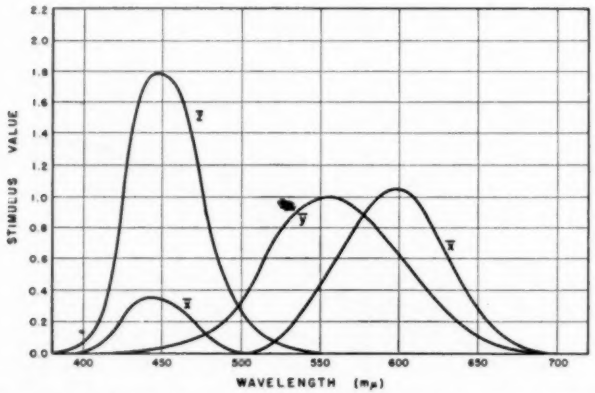

Fig. 2. Spectral distributions of the tristimulus functions of the ICI standard observer. These curves may be considered as the color responses of the visual mechanism, analogous to the red, green and blue sensitivities of a color print material.

tributions of the color responses are called stimulus functions. One response is primarily red-sensitive, one green-sensitive and one blue-sensitive, again like most color print materials. Figure 2 shows the spectral distributions of these functions as used in the system of the International Commission on Illumination. Apparently, then, a densitometer can be specified which will determine the effects of a transparency's absorptions on the amounts of these color responses, and therefore, on the color of the image. It is only necessary to replace, in the equations used for the print-density densitometer, the print-sensitivity distributions, $S(\lambda)$, by the color stimulus functions, $\bar{x}$, $\bar{y}$ and $\bar{z}$.[11] The densitometer then becomes a direct-reading color-

imeter except that it reads, rather than color-stimulus values, a density unit which is the negative logarithm of the ratio of a color-stimulus value, as reduced by the transparency's absorptions, to the stimulus value before that reduction. This unit has been called a *colorimetric density*.

In the current practice of color sensitometry, colorimetric densities are seldom determined. There are several reasons for this. One is that another type of densitometry to be discussed later (analytical densitometry measuring equivalent neutral densities) gives descriptions of images satisfactory for most purposes to which colorimetric densities would be applied. Another is that colorimetric characteristics of the image can be determined qualitatively by direct observation of the image, and such determination is often sufficient.

It is frequently desirable to compare two images with respect to their brightness, even when their colors are different. This is done by use of *luminous* density, which is the negative logarithm of the luminous (brightness) transmittance of the image, and is identical with the $\bar{y}$ density in the colorimetric system.

Arbitrary Three-Filter Densities

There are in widespread use in color densitometry many instruments in which densities are determined by using light filtered through red, green, and blue filters chosen only with the object of getting some kind of red, green and blue light. These densitometers do not read printing densities or colorimetric densities; they read an arbitrary kind of integral color density in which the color response functions employed are those which the particular filters, photocells, etc., happen to give.

These densitometers, and their readings, are quite satisfactory for some purposes. They will determine whether two images have identical colors, provided both images are formed of the same dyes. For if two images, formed of the same dyes, are matched in color, they must have identical spectral absorption curves; they will therefore have identical effects on the stimulus values of any color densitometer system. They will also have identical printing densities for any material. These densitometers are therefore satisfactory for comparisons of identical or nearly identical images. Some control applications require only this type of comparison. Consistency of color processing over a period of time is usually tested by examining the images formed at various times in identically exposed samples of the

same film. For determining whether the processing results are identical amost any density readings with red, green and blue light will do. They will determine in a general way the direction of any processing difference.

But the limitations of such densitometry should be recognized and kept in mind. The density readings cannot be safely used as direct indications of printing density or of image color; large errors may result, particularly in judging samples of high density. It is not safe to compare by means of these density readings a light image with a dense image. The two images may have identical sets of differences

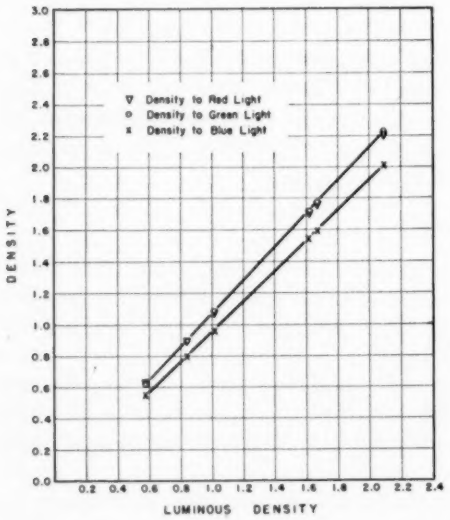

Fig. 3. Three-filter densities of a set of gray images in a direct-reversal color film. Red, green and blue densities for any given step have different values, and the differences vary with the absolute density level.

among their red-light, green-light and blue-light densities, yet be widely dissimilar in chromaticity (color without respect to brightness). Or conversely, they may be identical in chromaticity yet have widely dissimilar sets of density differences. Figure 3 illustrates this latter case; it shows densities of a set of gray images in a direct-reversal color film, determined by using a visual densitometer equipped with Wratten filters Nos. 25 (red), 58 (green) and 47 (blue). The densities to red and green light are very nearly the same, but the differences between these densities and the density to blue light varies from 0.08 to 0.22.

Spectral Densities

Integral densitometry includes the measurement of spectral density, an integral density of increasing importance. Spectral densities are those measured by use of light of a single wavelength.

Spectrophotometers measure spectral densities, or spectral transmittances from which spectral densities can be computed. A curve of spectral transmittance vs. wavelength is a complete description of the absorption properties of an image. It is basic information. From it can be computed the density value of the image in any kind of integral density unit for which the weighting factors are known. The accuracy of results thus obtained is usually better than is obtained from instruments in which automatic weighting has been incorporated. Thus, in colorimetry the effects of an absorber in reducing stimulus values of an illuminant are most accurately determined by using the spectral transmittance curve with standard weighting functions.[11] The effects of an absorber in reducing the actinic power of a beam of light can be similarly computed. But there are two limitations on the usefulness of this method: (a) Too much time and labor are required in determining the spectral transmittance curve and in the subsequent computations, and (b) too few spectrophotometers can determine the spectral densities of the densest images required in color sensitometry.

Densitometers for determining spectral densities are discussed in Section V. The usefulness of spectral densities is the result of two important features: (a) Means of measuring spectral density can be rigidly specified, and (b) spectral densities are additive. Because the methods of measurement can be rigidly specified, spectral density is useful for writing specifications of image characteristics. If two parties agree on what certain spectral densities of an image should be, they can independently test for conformance with specification with good prospect of agreement in result. Other types of density are more arbitrary in nature; they depend on specification of such things as spectral sensitivity of a print material, the spectral absorption characteristics of a set of dyes, or the color-vision characteristics of the densitometer operator. The fact that spectral densities are additive means that the densities of two separate absorbers can be measured with assurance that the sum of those two densities will give (excepting surface and scatter effects) the density of the superimposed combination of those two absorbers. This feature greatly simplifies

calculations of characteristics of transparency combinations. Because of their additivity, spectral densities are essential data for one type of analytical densitometry.

Analytical Color Densitometry

Integral densities always describe some action of the color image as a whole. They do not directly yield information about the image composition in terms of the individual amounts of the dyes. Some knowledge of this content is often useful. When the processed images are not right for a given purpose, it usually is necessary to apply corrective measures that affect the concentration of the image substances. It is useful to know which components of the image are incorrect, and in what direction and degree they depart from their required amounts. Such information is obtained by analytical densitometry.

A subtractive color process image usually is thought of as made up of a cyan dye image, a magenta dye image and a yellow dye image. With certain reservations, this concept is essentially correct. The cyan dye primarily absorbs red light, the magenta dye primarily absorbs green light, and the yellow dye primarily absorbs blue light. But to a smaller extent the cyan dye also absorbs green and blue light, the magenta dye absorbs blue and red light, and the yellow dye absorbs green and red light. Integral density measurements show the total effects of all these absorptions. Analytical density measurements determine the individual amounts of each of the three dye deposits. Instrumental means of making these measurements are discussed in later sections of this report. The amounts of dye deposits or other image components thus determined can be expressed in any of several useful density units.

Spectral Analytical Densities

Perhaps the simplest of these units is a spectral density of the dye deposit; that is, the amount of dye is expressed as its spectral density at some one wavelength. Figure 4 shows as curve N the spectrophotometric curve of a gray image formed by a typical subtractive color process. Curves Y, M and C show spectrophotometric curves of the yellow, magenta and cyan component images which together form the gray. At λ_1 (440 mμ) the integral spectral density of the gray image is 1.82. That is the sum of the density contributions, at that wavelength, of all three dyes. The contribution of the yellow dye is only about 1.33. This figure, $Y = 1.33$, is an analytical den-

sity. It is the density of the yellow component of the gray image, expressed in terms of its absorption at λ_1. Similarly, the density of the magenta component of this image is 1.38 if it is expressed in terms of absorption at λ_2 (535 mμ), and the density of the cyan component is 1.84 if it is expressed in terms of absorption at λ_3 (670 mμ). Means of obtaining these analytical density values from the integral density measurements are discussed in Section VI of this report.

The density figures obtained in this example ($Y = 1.33$, $M = 1.38$, $C = 1.84$) are not particularly descriptive of the appearance to be expected of the integral image; it is not evident from them that they are the components of a gray. For some purposes this need not be

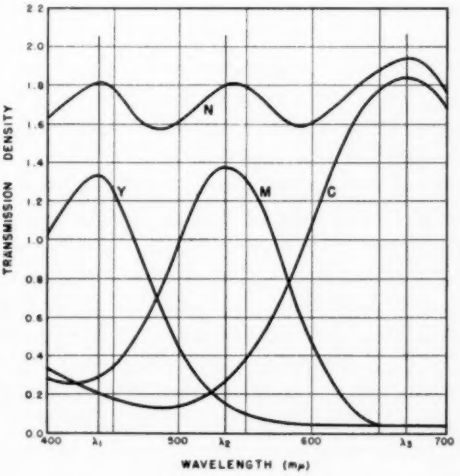

Fig. 4. Spectral densities of a gray image (N) (visual density 1.72) obtained in a subtractive color process, and of its yellow (Y), magenta (M) and cyan (C) component images.

evident. If a specification of the desired contents of the image has been made in these terms of spectral analytical density, the density figures permit comparison, component for component, of the image obtained with the one desired. If the desired components were $Y = 1.33$, $M = 1.53$ and $C = 1.84$, the analysis reveals that only the magenta component is in error, and that it is 10% low. This is definite and sometimes adequate information. It is for some purposes a better comparison of specified and realized images than would be obtained by use of integral spectral densities. In terms of integral spectral densities, the specification of the image with 10% more magenta would have called for densities of 1.85, 1.95 and 1.94, at λ_1,

λ_2 and λ_3. The measured spectral integral densities, 1.82, 1.80 and 1.94, show that the obtained density to blue light is low by 1.6%, the density to green light is low by 7.7%, and the red absorption is correct. It is not evident that the deviations from specified densities are caused by having 10% too little magenta.

Equivalent Neutral Densities

The usefulness of the analytical density values can be greatly increased by selecting density units which give a better description of the integral image. The unit in most widespread use is variously called "gray equivalent density" after Heymer and Sundhoff,[12] who first published its description, or "equivalent density" after Evans,[13] who independently developed the concept in this country, or "equivalent neutral density." Evans defined the equivalent density of a component of a subtractive color process as the luminous density it would have if it were converted to a gray by superimposing the just required amounts of the other components of the process. If the amounts of the components of an image are expressed in this unit, each of the density figures tells how dense a gray that component can form. In the example of analysis already given, the visual density of the gray represented by curve *N* is 1.72; that is, to the eye, the somewhat selective absorber, *N*, with spectral densities ranging from 1.58 to 1.94 looks like a nonselective gray of density 1.72. In terms of equivalent neutral density, each of the component absorbers, *Y*, *M* and *C*, of this image also have a density of 1.72.

The most valuable feature of the equivalent neutral density unit is this: Three components which together will make a gray must all have the same equivalent neutral density. Comparison of the equivalent neutral densities of the components of an image will therefore tell directly whether that image is gray (assuming illumination with a specific light quality). If the three component densities are not identical, the comparison will show the direction and amount by which the image deviates from gray, though not in standard colorimetric terms. To a close approximation, specification in terms of equivalent neutral density permits comparison of the chromaticities of light and dark images, since the same set of differences in densities means nearly identical chromaticities.

The fact that equivalent neutral densities show directly the visual densities of grays makes this unit of considerable advantage in work

requiring computation of brightness ratios in the images as functions of brightness ratios in the original scene, that is, in "tone reproduction" problems. These problems are met in motion picture practice in the adjustment of duplication processes and in special effects work.

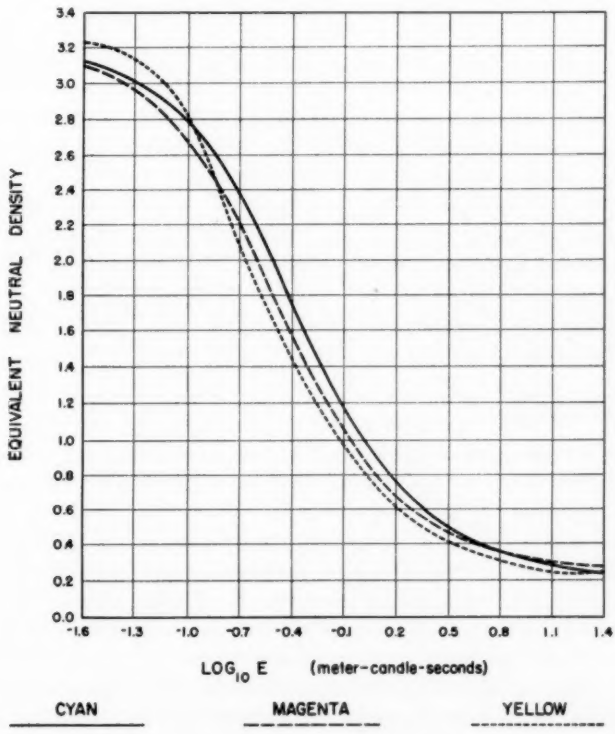

Fig. 5. Analytical density plot of the characteristic curves of a direct-reversal color film. Equivalent neutral densities of the images of a gray scale are shown against the logarithms of exposure.

Figure 5 shows a typical set of characteristic curves of a direct-reversal color film, showing the gray scale densities plotted in units of equivalent neutral density. Instrumental means of obtaining equivalent neutral density analyses of subtractive process images are discussed in later sections of this report.

Equivalent Neutral Printing Densities

For materials intended to be printed rather than viewed, use is sometimes made of an analytical unit called "equivalent neutral printing density."[14] A nonselective gray absorber always has identical red, green and blue printing densities. But because a subtractive-process gray is spectrally selective (as curve *N* of Fig. 4), its red, green and blue printing densities may be quite different, depending on the portions of the spectrum used in the printing process. But just as a visual gray can always be made up of the subtractive process dyes, so a dye combination can be made up which will have equal values of red, green and blue printing densities. This will be a printing neutral, rather than a visual neutral. All the dye components will have identical equivalent neutral printing densities, rather than identical equivalent neutral (visual) densities. The features of this density unit in printing systems are entirely analogous to those of equivalent neutral density in visual systems, and the advantages of the unit as a descriptive means for printing processes are obvious.

Systematic Errors

Some warnings should be noted in connection with determination of analytical density. In setting up the analytical system, simplifying assumptions are always introduced. Some conditions are always assumed which are not quite met by the process, and it must be realized that combinations of small errors introduced by these assumptions can produce appreciable errors. It is difficult to determine exactly the nature of the independent components of a color process image. Color film images are not made of only three absorbers, the yellow, magenta and cyan dyes usually assumed. There are always, in addition, stains introduced in the manufacture or processing of the film, and there are always surface effects which act like absorbers. Therefore, most analysis systems consider a fourth absorber to be present; in the absence of exact information this is usually considered fixed, i.e., present in the same amount in all images. The characteristics of the remaining components are derived usually from measurements of single-dye images; frequently it is difficult to insure that these single-dye images are really representative of the components of the process. If they are not, errors will appear in the analysis, dependent in kind and magnitude on the type of instrument used. Also, in one type of analysis it is assumed that the equivalent neutral den-

sity of a dye component is a linear function of a spectral density of that component; this is never exactly true although the error of the assumption is frequently small.

It should be kept in mind that analysis into component dyes is only one of a number of possible modes of analysis. In theory, any set of independent variables acting on the processed image can be used as analysis components for that image. In practice, most sets other than the component dyes are too difficult to handle to be of much use.

Integral Densitometry vs. Analytical Densitometry

Both integral and analytical densitometry have important uses in sensitometric operations. Integral densitometry measures performance; analytical densitometry measures composition. For thorough sensitometric description of an image both measurements are required. But both are seldom made. Through experience with a product, the general nature of correlations between composition and performance becomes sufficiently evident that for most tests one measurement is made to serve both purposes. The choice of which kind to make must be answered in each individual case by considering (a) the relative importances of performance and composition data, (b) the apparatus and personnel available for the densitometry, (c) the rate at which determinations must be made, and (d) the importance of high precision of measure and of good agreement among several instruments.

In general, for equal precision of measure, integral density measurements require somewhat less care and simpler apparatus than analytical determinations, and can be made faster. In analytical determinations, inter-instrument differences can be minimized by calibration or by alteration of transfer functions; analytical densities therefore may show better inter-instrument agreement than integral densities. But a set of integral densitometers can be made to agree excellently by applying small systematic adjustments to the readings of each so that the resulting data match a mean result. In spite of these apparent practical advantages of integral densitometry, analytical densitometry also is widely used. This is strong indication that for some purposes the advantages of analytical density data are real and worth the expenditure of considerable effort in their procurement.

V. DENSITOMETER DESIGN PRINCIPLES

The instruments used to determine the density values which describe dye images on color film are generally called "color densitometers." General requirements that must be met by such instruments follow from the principles discussed in the preceding section: For integral densitometry, the spectral response must have specific characteristics that may depend on the intended application; for analytical densitometry, the measurement of each image component must be independent of the amounts in which the other two are present; in both cases, the optical geometry of the instrument must be so arranged that the effects of image scattering can be correctly evaluated. The purpose of this section is to consider the basic components of such instruments, and to review the factors which influence their design. As the art progresses beyond its present unsettled state, specific methods and designs may establish their superiority; meanwhile, no preferred or recommended equipment will be indicated in this report.

Instruments in Current Use

Current practice in the motion picture field includes the general use of three types of instruments. The first and most common type is a three-filter modification of a black-and-white densitometer, as for example the Western Electric RA-1100 densitometer.[15] These instruments measure integral densities. Where the filters are more or less arbitrary, the densities are subject to the limitations discussed in Section IV. By more careful selection of filters, printing densities for specific materials, or colorimetric densities, may be approximated within limits imposed by the over-all sensitivity of the instrument. The Ansco color densitometer[31] employs filters with very narrow transmission bands and thus measures approximately spectral densities at the wavelength of peak transmission of these filters.

Spectral densities at any desired wavelength may be determined with laboratory devices such as the Beckman[17] spectrophotometer and the Cary[18] and General Electric[19] recording spectrophotometers, but these instruments are not designed for use in routine densitometry.

The third type of instrument in use at present is the visual analytical color densitometer described by Evans[13] which is calibrated to yield direct readings of equivalent gray densities. Its use is restricted by the requirement that each of its three dye wedges must have at all

densities spectral absorptions which match the absorption characteristics of the corresponding dye in the film under investigation; thus different sets of wedges are required for different color films. The same limitation applies to the Agfa photoelectric analytical color densitometer described by Schneider and Berger.[20]

Other instruments are in use for special work and laboratory investigations, but these three are the representative classes.

Basic Components

All of these instruments can be regarded as made up of certain basic components. These are briefly listed below; later the most important functional requirements will be discussed for each:

(1) Light sources, which provide the radiant energy used to analyze the dye image,

(2) Spectral selectors, which pass the desired wavelength band of radiation from that source (most commonly a set of filters; alternatively a prism or grating with associated optics and apertures),

(3) Wedges or other attenuators, which are often used to adjust to equality the beam of light transmitted by the specimen and a comparison beam,

(4) Receivers, which detect the radiant energy transmitted by the sample and convert it to a sense perception (visual instruments) or to an electrical signal (photoelectric instruments),

(5) Indicators, which in direct-reading instruments show the density value corresponding to the output signal, or which in null systems show that the measuring and comparison beams have been equated by proper adjustment of the wedges, and

(6) Recorders, which can range from a simple strip chart device attached to an instrument such as the Ansco color densitometer or the General Electric spectrophotometer, up to complex systems which transform the integral densities measured by the photocell into analytical densities and automatically plot either one or both of these sets of densities.

Light Sources

The primary requisite for a light source for color densitometers is that it must produce a sufficient quantity of energy in the desired wavelength regions. In many instruments, it is further required that the output of this source at each wavelength remain constant over long periods of time; if this is not the case, special provisions must be

made to insure stability in both direct-reading instruments and null instruments. Tungsten lamps operated below rated voltage are excellent from the standpoint of constancy of output and have a continuous spectral distribution suitable as a starting point for most instruments. Unfortunately, a high percentage of their energy is put out as heat which must be dissipated. Accordingly, densitometers using tungsten lamps often require forced ventilation of the lamp house and heat-absorbing filters in the measuring beam ahead of the main filter system and the sample.

Other sources of light are under consideration, notably the mercury-cadmium arc. This has the advantage that a considerable portion of its output is concentrated at wavelengths of which three are approximately in the centers of the three spectral regions of most general interest. These wavelengths are considered for use in the standardization of integral densitometry. The efficiency of the mercury-cadmium arc as a source of these particular radiations is much higher than that of tungsten, and the heat problem is accordingly very much less severe. Stability of output is somewhat more difficult to attain with this type of gas discharge lamp than with tungsten lamps, but practical experience indicates that control circuits can be constructed which will hold it within satisfactory limits.

Gas discharge lamps, unlike incandescent lamps, are not concentrated sources; their radiant emission occurs within a rather large volume. In densitometers which use such sources it therefore may be difficult to provide sufficient concentration of energy at the sample plane to permit measurement of small sample areas.

Spectral Selectors: Filters

Filters are used in most integral color densitometers to modify the spectral composition of the beam in accordance with the theoretical requirements stated in Section IV. The simplest specification is to use any set of three filters, of which each isolates somewhat less than one-third of the visible spectrum. The red, green and blue beams so produced establish integral color densities that are peculiar to that specific densitometer and cannot be satisfactorily compared with densities read on other types of densitometer. Nevertheless, such arbitrary three-filter densities may be quite useful for many applications that are within the restrictions pointed out in Section IV.

More stringent requirements must be met by the filters in instruments intended for the measurement of printing densities or colori-

metric densities. The necessary identity (see Section IV) of the products, $J(\lambda)\, e(\lambda)\, S(\lambda)$ and $J'(\lambda)\, e'(\lambda)\, S'(\lambda)$, demands filters that produce in the densitometer a transfer efficiency

$$e'(\lambda) = \frac{J(\lambda)\, e(\lambda)\, S(\lambda)}{J'(\lambda)' S\ (\lambda)}.$$

The quantities $J(\lambda)$ and $e(\lambda)$ are determined by the printing system, $S(\lambda)$ is a property of the print stock, while $J'(\lambda)$ and $S'(\lambda)$ are characteristics of the source and receiver of the densitometer. These last two quantities are generally fixed by other design considerations, so that the function $e'(\lambda)$ is rigidly specified. The selection of a combination of filters that yield a reasonably close approximation to the required spectral properties is a rather challenging problem for the instrument designer; when the desired filter cuts are achieved, the efficiency is often so low that the sensitivity of the radiation receiver is insufficient to measure the transmitted light with the necessary accuracy.

Similar problems are encountered in the selection of filters for instruments that are to yield approximate spectral density measurements. Here the pass-bands will be made as narrow as feasible, consistent with the requirement of sufficient output energy to permit accurate measurement. The location of the peak wavelengths for measurements of this type is currently under consideration by the Committee on Still Photography, Z38, of the American Standards Association. At certain specific wavelengths, a narrow spectral composition of the measuring beam can be produced with fairly high efficiency by using a "line source," such as a mercury-cadmium arc, together with filters that isolate the strong individual lines in the spectra of these sources.

An important practical requirement for all filters used in color densitometry is that they should be stable. Their spectral characteristics must not change as a result of exposure to the heat, humidity, and radiant energy that they will encounter in the densitometer. As far as possible, glass filters should be used; in all cases the beam transmitted by the filters should be restricted to the smallest amount of energy which will meet the requirements of the system. Filters should be protected from infrared as mentioned earlier, and, equally important, from ultraviolet in the case of sources which emit considerable energy in that region. Fluorescence in any of the filters or in the sample introduces special problems that must be analyzed before

density readings made with them are accepted as representative of the film under normal conditions of use.

Spectral Selectors: Dispersion Systems

Spectral dispersion by prism or diffraction grating provides an alternative method of modifying the spectral composition of the measuring beam in integral color densitometers. In these instruments energy from the light source is spread out into a spectrum from which certain wavelength regions can be selected by masks or slits. At each wavelength, λ, the height of the opening in the mask controls the amount of radiation transmitted by the mask, so that any spectral transfer function, $e'(\lambda)$, can be established by proper shaping of the opening in the mask. Densitometers based on this method of spectral selection are therefore readily adaptable to the measurement of any desired type of printing or colorimetric density, including luminous density.

If only a single wavelength band is permitted to pass through a narrow slit, the resulting radiation is said to be monochromatic and such radiation may be selected at any desired wavelength by proper positioning of the slit. As the slit is widened, more radiant energy is transmitted, but the spectral purity of the beam suffers. If such an instrument is used with a light source that has a continuous spectrum, and is so arranged that spectral densities can be read at any wavelength, it is called a spectrophotometer. A "spectrophotometric curve" showing the spectral density of a photographic image at all wavelengths is a complete and basic description of the absorption properties of that image. A spectrophotometer of adequate sensitivity is the ideal laboratory instrument, but it suffers from the disadvantage that its use is too complicated and time-consuming for routine sensitometry. The effects of scatter must be kept in mind; spectrophotometer results are strictly applicable only to situations in which scattered radiant energy is evaluated in the same way as in the spectrophotometer.

Wedges

Wedges are variable absorbers used to reduce the intensity or change the color of the radiation transmitted by the optical system of a densitometer. They are generally found in visual instruments. In electronic densitometers it is often easier to accomplish the equiv-

alent attenuation by electrical means, but for certain purposes wedges may also be employed. The best known form of wedge is that found in the Capstaff visual densitometer[21] for black-and-white film. This is a circular glass plate carrying an arc-shaped silver image whose density varies from a minimum value slightly above zero to a maximum value above 3.0. The density variation is approximately linear with the angle through which the plate is rotated.

Similar gray wedges can be made of gelatin containing gray dye mixtures or colloidal graphite. Yellow, cyan and magenta wedges containing graded amounts of the dyes used in specific color processes are used in the direct analytical densitometry of those processes.

The manufacture of wedges is difficult, and calibration of the individual wedges is necessary for precise work. Such calibrations must be periodically checked to make sure that the wedge characteristics have not changed as a result of fading or other effects. In dye wedges used for analytical color densitometry, careful spectrophotometric checks must be made to insure that the spectral transmittance characteristics of the wedge are at all densities identical with those of the corresponding dye in the photographic image. The fact that certain types of photoelectric instruments do not require wedges is a distinct point in their favor.

Receivers

The receiver for a visual densitometer is the observer's eye. Care must be taken to insure that the operator has no abnormalities of color vision. This is particularly important in cases where the observer's task involves the matching of two fields that are not spectrally identical. Operator fatigue tends to reduce the accuracy of photometric and colorimetric matches, and visual instruments are therefore not suitable for the evaluation of large quantities of test images.

Receivers for electronic instruments include many of the usual types of photocells or photo-multiplier tubes. Since most of the densitometry in a color process occurs in the visual region of the spectrum, receivers which are sensitive to infrared or ultraviolet are required only for special purposes, such as sound track or integral silver mask analysis. In fact, the sensitivity which all photoelectric surfaces tend to have in these regions is usually a disadvantage, and great care must be taken in the filter system to insure that the cell is receiving only those wavelengths which it is desired to utilize. This is

a particularly difficult problem in the case of filters made from dyes, since almost without exception their infrared transmission is high, and even the S-4 surface has considerable residual sensitivity in the near infrared region. Infrared absorbing filters are therefore included in the optical path of most photoelectric color densitometers. These may be glass, such as Corning 9780, or liquid, such as cupric chloride solution. These near infrared absorbers should not be confused with heat-absorbing filters which usually are also included in the optical path.

The photocell is associated with an amplifier whose output operates an indicating instrument or a recorder. These amplifiers are varied in type, depending on the functional design of the densitometer. In the Ansco instrument the radiant energy transmitted by the sample arrives on the photocell at a constant rate proportional to the transmittance of the sample. The circuit associated with the photo-multiplier tube receiver automatically controls its dynode voltage in such a manner that the photo-multiplier tube anode current is held constant regardless of specimen density. The output of the instrument is measured in terms of dynode voltage which is essentially linear with specimen density. In the Western Electric instrument, radiant energy from an interrupted beam arrives at the photocell as an alternating signal of which the amplitude is proportional to the transmittance of the sample. Here a two-element vacuum phototube and a normal a-c amplifier produce a linear response proportional to transmittance. This is converted to density by a nonlinear indicator.

A somewhat simpler situation exists in instruments in which the energy in the sample beam is adjusted by an optical attenuator until it matches a fixed comparison beam. If the two beams are directed onto the photocell in rapid alternation, a sensitive a-c amplifier will detect any small difference between the energy in the two beams. Zero output will be obtained only when the beams are matched. When this condition is attained, the density of the sample is read from a scale which measures the position of the optical attenuator. Densitometers, such as the General Electric spectrophotometer, which utilize this design principle, are often called *null* instruments.

In general, the combination of receiver and amplifier should have the maximum of sensitivity in the desired wavelength band and minimum sensitivity elsewhere with the maximum degree of stability possible. This is particularly important in instruments which

are not of the null type, as any change in over-all sensitivity of these units produces a shift in calibration.

Indicators

In photoelectric color densitometers, the desired information about the sample is contained in an electrical signal which must be conveyed to the observer by some sort of indicating or recording device. Where the amplifier puts out a signal that is directly proportional to density, an ordinary electrical measuring instrument will show a deflection proportional to density. The scale on such a meter can be marked directly in density. If the amplifier output is proportional to transmittance, the scale of the same type of meter might be divided into logarithmic intervals so as to yield density readings. However, a scale like that would be so closely spaced at one end that the precision of high *density* readings would be low. This difficulty can be minimized by using electrical meters with special nonlinear movements in which the deflection is approximately proportional to the logarithm of the input signal. Such meters are generally used over a 10:1 signal range, so that they cover a density interval of 1.0. Signals that exceed this range are reduced by factors of 10, 100 or 1000 through electrical or optical attenuators, so that densities in the ranges 0 to 1, 1 to 2, 2 to 3, and 3 to 4 can all be read by appropriate settings of a range control.

In null instruments, the electrical indicator serves only to show that a balance has been attained between two beams. The principal requirement is high sensitivity so that even a small amount of unbalance may be detected. The densities themselves (or readings from which they can be computed) are obtained from scales attached to the wedges or other attenuators which are used to establish balance between the two beams. An attempt is generally made to provide a scale that is approximately linear with density over the range of the instrument.

Recorders

Recorders can be attached to any electronic color densitometer. The Cary and General Electric spectrophotometers are normally equipped with recording means. Recording is especially desirable in spectrophotometers because these instruments can determine spectral densities at all wavelengths within a large spectral range. These density values can be shown as functions of wavelengths on spectro-

photometric curves. On a non-recording instrument many separate readings would have to be made and subsequently plotted to obtain such a curve. By the use of a recorder it can be plotted directly by the machine.

The Ansco instrument is so designed that an ordinary Brown one-milliampere linear recorder can be directly attached. Density recorders generally can be thought of as modifications of recording power level indicators, such as are standard in the communications field. Their application to the particular circuit of any densitometer can be worked out for each case by normal electrical engineering methods, although the range and stability requirements may be more severe than for the usual acoustical applications.

Geometrical Design Factors

The scattering of radiation by the dye image in color films has an important influence on the effective absorption of a film sample in different optical systems. This circumstance has already been discussed in Section IV where it was pointed out that evaluation of the scattered radiation in the color densitometer should not be substantially different from that in the optical device in which the film is to be used. It was further indicated that the use of apertures larger than the minimum required for acceptance of the cone of principal scattering would involve only small errors.

The instruments now available exhibit considerable variation in the mode of illumination of the sample, and in the arrangement used to collect the transmitted radiation. The suitability of any particular geometrical design for a specific use can be checked by tests in which density readings of the given color film materials are compared with its performance in the optical system (printer, projector, viewer) for which it is intended.

The only geometrical arrangement that has so far been standardized is that which measures *diffuse* transmission density. This is defined and techniques for its measurement are specified in American Standard Z38.2.5. The introduction to this standard points out the possibility of applying corrections to the calibration of *any* type of densitometer so that it will yield diffuse density values for any *single* type of photographic material. In general, new corrections must be determined if accurate readings are desired on a different photographic material. In color products, the correction factor may also vary with

the image color in any one material. For example, the correction factor may be larger for yellow images than for blue ones.

Systems for Integral Densitometry

Color densitometers are functional assemblies of the basic components which have been discussed. The selection or design of specific components and their integration into an effective system constitute the task of the instrument designer. Without considering structural, optical or electrical details which may be seen in published

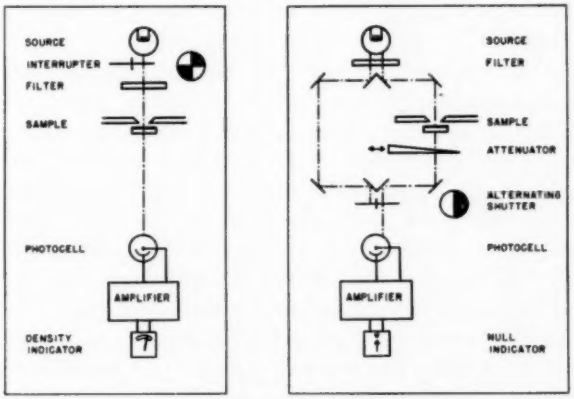

Fig. 6. Schematic diagrams of basic densitometer designs: (a) direct-reading instrument, (b) null instrument. In a direct-reading instrument, the photocell output is used to measure the density of the sample. In a null instrument, the photocell serves only to indicate balance between beams; the density of the sample is measured by the attenuator.

descriptions of current instruments or obtained from their manufacturers, the remainder of this section will deal with some of the general features of complete densitometer systems.

Integral color densitometers may be subclassified in numerous ways; one of the most significant distinctions is that between direct-reading instruments and null instruments. This fundamental difference which has already been referred to in the discussion of basic components is schematically illustrated in Fig. 6.

A direct-reading instrument performs a measurement of the radiant energy transmitted by the sample. Usually, this measurement is

preceded, at the time of calibration, by a measurement of the radiant energy incident upon the receiver with no sample in the beam. The instrument is adjusted until the density reading obtained with no sample is zero; subsequent measurements with film samples in the beam are then made with respect to that reference level. The distinguishing features of direct-reading instruments are the single-beam optical system and the direct quantitative evaluation of transmitted radiant energy as a fraction of (or density difference from) a previously established no-sample reference level. The human eye is not capable of performing direct quantitative measurements of radiant energy, and direct-reading instruments are therefore based on photoelectric receivers.

In a typical direct-reading instrument, shown schematically in Fig. 6a, the primary output of the receiver may be an alternating signal produced by an intermittent ("chopped") measuring beam. After amplification and rectification, a d-c signal proportional to transmittance is obtained. By applying this signal to a logarithmic meter, a deflection approximately proportional to density is produced as final indication. Other systems of obtaining a uniform density scale have been used with success. The method of producing a logarithmic output signal by using a photo-multiplier tube in a special circuit has already been mentioned in discussing basic components.

In a null instrument, the receiver serves only to establish the equality of response to the radiant energy contained in two separate beams, and, alternatively, to provide a sensitive indication of mismatch between these beams. Equality of response is brought about by calibrated reduction of the response from one of these beams, usually by means of optical attenuators (silver wedges, polarizing prisms, variable apertures). As shown in Fig. 6b, such an attenuator may be in the same beam as the sample; the combined absorption of sample and attenuator reduce the radiant energy until the response is identical with that from a fixed comparison beam. Or the attenuator may be in the other beam, so that the response from the comparison beam is reduced until it matches that of the sample beam. In either case, the density of the sample is read or computed from a scale indication on the attenuator. In situations where the spectral quality of the energy is identical in the two beams, as in the measurement of spectral densities, the eye may serve as a simple and sensitive receiver, although here too photoelectric instruments will be preferred for routine operations.

Systems for Analytical Densitometry

The direct measurement of analytical densities is based on the principle that the absorption of the dyes in the film sample can be matched by the combined absorption of three wedges, each of which contains varying known amounts of one of the three dyes of the process in question. The simplest situation is shown in Fig. 7 where the left beam contains the sample, and the right beam the set of wedges. When each of the wedges is set to its proper position, their combined absorption will match that of the sample, and the two beams will be indistinguishable. If the eye is to be used as detector, the two beams will be presented for observation in a split field optical system. The task of the observer is then similar to the operation of a

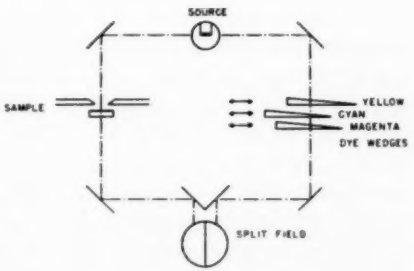

Fig. 7. Schematic diagram illustrating the principle of an analytical color densitometer. The absorption of the sample in the left beam is matched by the combined absorption, in the right beam, of three wedges, each containing one of the three process dyes.

visual colorimeter: The three wedge adjustments must be manipulated until a color match is obtained. When this is achieved, the position of the wedges will indicate yellow, magenta and cyan analytical densities, or, with proper calibration, the corresponding equivalent neutral densities.

An instrument based on this principle of operation is properly described as a null instrument, but it differs in one fundamental point from the null instruments used for the measurement of integral densities. In the former instruments, equality of response could be secured by a single adjustment; in the present case we have three independent variables. In integral densitometers, three numbers describing the color film image are obtained by three successive operations with three measuring beams differing in spectral quality. Each of the three operations involves only one variable. In direct analytical densitometers, three numbers providing an alternative

description of the color film image are obtained in a single operation involving three variables.

Therefore, if the eye is to be replaced by a photoelectric receiving system, this system, like the eye, must be capable of judging the equality of two beams with respect to three parameters. In the instrument described by Schneider and Berger[20] this is accomplished by inserting red, green and blue filters before the photocell in rapid alternation, so that the two instrument beams are effectively compared first by a red-sensitive photocell, then by a green-sensitive photocell, then by a blue-sensitive photocell. If in each case the response from the sample beam is equal to the response from the wedge beam, the two beams are satisfactorily matched. The three filters used with the photocell will be selected to provide maximum sensitivity in the detecting system to small errors in the setting of the wedges.

A somewhat different arrangement of the wedges is used in the visual analytical densitometer described by Evans.[13] This again is a null instrument, but the wedges are in the same beam as the sample, and the comparison beam is fixed. This has the great advantage that the appearance of the split field at the match point is the same for all samples. The fixed comparison beam corresponds roughly to a sample with maximum yellow, magenta and cyan dye deposits. When a sample with smaller amounts of dye is inserted, the balance is restored by adding the absorption of the dye wedges. The amount so added yields an inverse indication of the amount present in the film sample. A further feature of the Evans instrument is the presence of a silver wedge which can be used to substitute a nonselective silver deposit for a gray combination of wedge dye deposits. In the evaluation of nearly gray film samples, this substitution circumvents errors which tend to occur at high densities in dye wedges.

The crucial component of all direct analytical densitometers is the wedge set. The preparation of suitably graded wedges in which the dye images are and remain strictly equivalent to those encountered in actual film samples is an extremely difficult task which must be separately undertaken for each color process to which the densitometer is to be applied. Once such wedges are available, analytical densitometers provide descriptions of the film image composition in terms that are particularly valuable in investigative work.

VI. TRANSFORMATIONS BETWEEN INTEGRAL AND ANALYTICAL DENSITIES

Instruments for the measurement of integral and analytical color densities have been separately discussed in the preceding section. The difficulties encountered in the direct determination of analytical densities suggest the possibility of utilizing the relationship between integral and analytical densities to compute the latter from the former.[12,23] Where this course is adopted, samples are read on an instrument that yields integral spectral densities. For many purposes, especially in routine control, these are used directly; for other applications, where description in terms of the amounts of the individual dyes is more useful, the integral spectral densities are "converted" to analytical densities by computation.

The general nature of the relationship between these two types of color density has already been considered in Section IV. The problem now is to reduce this to a quantitative formulation which is suitable for routine computation.

Densities of Superimposed Dye Images

Figure 8 shows the spectral densities of the yellow, magenta and cyan dye deposits in a sample of multilayer film. This sample differs from the one illustrated in Fig. 4, both in the kind and in the amount of the dyes it contains, but the diagrams are similar in showing the variation of spectral density with wavelength for each of three components of a subtractive image. The sample shown in Fig. 8 is a gray sample; the yellow, magenta and cyan dyes produced in this process are present in just the right amounts to make the sample appear achromatic in a given reference illuminant (3000 K in the case of Fig. 8). The gray image which they form has a visual density exactly equal to 1.00.

This appearance is the result of the combined action of the three component dye images on the radiation passing through the film. At each wavelength, each of the dyes acts independently of the others in absorbing radiation, and the total density at each wavelength is equal to the sum of the densities of the components. At 535 mμ, for example, the density of the yellow dye deposit is 0.09; that of the magenta, 0.76; and that of the cyan, 0.17. The total density, at 535 mμ, of the image is $0.09 + 0.76 + 0.17 = 1.02$. This total or "in-

tegral" spectral density of the three superimposed dye components is the quantity plotted as the curve marked *N* in Fig. 8; it is identical with the integral spectral density of the image that would be determined in a spectrophotometer. This wavy horizontal curve can thus be alternatively thought of as a spectrophotometric curve showing the integral spectral densities of the gray image, or as a plot, wavelength by wavelength, of the sum of the spectral densities of the yellow, magenta and cyan components of the image.

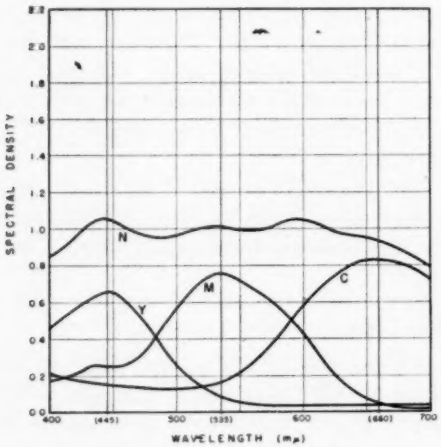

Fig. 8. Spectral densities of yellow (*Y*), magenta (*M*) and cyan (*C*) dye images obtained in a subtractive color process. Superposition of these images yields an image (*N*) that appears gray and has a visual density of 1.00.

Table II. Spectral Densities of the Dye Image of Fig. 8

(1) λ	(2) *N*	(3) *Y*	(4) *M*	(5) *C*
445	1.06	0.66	0.24	0.16
535	1.02	0.09	0.76	0.17
660	0.93	0.04	0.05	0.84

When the complete dye image is to be described by integral spectral densities, three such densities, at three different wavelengths, are generally sufficient. Table II lists three such wavelengths in Column 1, and the corresponding integral spectral densities in Column 2. The remaining columns show the individual spectral densities of the dyes. The choice of the three particular wavelengths has been arbitrary. They coincide with the absorption peaks of the three dyes, but this is not a rigid requirement. In practice, any three wave-

lengths in the regions of principal absorption of the three dyes will be acceptable, and plans are under discussion to adopt three standard wavelengths for use in all instruments.

Density as a Function of Dye Concentration

A sample with denser dye images is shown in Fig. 9. Here the yellow dye deposit has been increased until its spectral density at 445 mμ is just twice as large as in the earlier sample, *i.e.*, 1.32 instead of 0.66. If the yellow dye deposit in this process behaves in accordance with elementary theory, its spectral density at all other wavelengths will also be exactly twice its former value, and the complete yellow

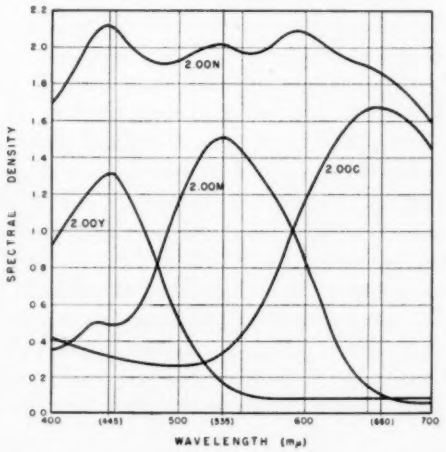

Fig. 9. Spectral densities of yellow, magenta and cyan dye images that have exactly twice the absorption of the images of Fig. 8. Superposition of these components produces an image whose spectral densities are exactly twice those of *N* in Fig. 8, but this image is not exactly neutral nor is its visual density exactly 2.00.

curve of Fig. 9 is simply the result of multiplying by two all the ordinates of the yellow curve of Fig. 8.

The requirement here involved is generally stated by saying that the dye deposit obeys *Beer's Law*, although strictly speaking, it is only necessary that the spectral density, $D(\lambda,k)$, as a function of wavelength λ and concentration k can be represented as the product $f(\lambda)\cdot g(k)$ of two separate functions. Even this less stringent requirement is followed only approximately by actual dye deposits.

If the magenta and cyan deposits are also assumed to follow this relationship, and if their spectral densities are similarly multiplied by two, the spectral densities of all three dye images and their sum will be as shown in Fig. 9. The shape and position of the top curve of

Fig. 9, which has been obtained by adding the spectral densities of the three dye components, suggests that the film sample it represents will be approximately a gray of density 2.0. The elementary theory of analytical densitometry assumes that it will be strictly achromatic in the reference illuminant, and that its density will be exactly 2.00. This is not rigorously true, even for dye deposits which follow Beer's Law. The departures for a number of spectral absorption curves have been investigated by MacAdam[22]. In actual photographic processes these departures are generally considered so small as not to interfere with the usefulness of densities derived on the basis of elementary theory.

The analytical densities of the dye deposits shown in Figs. 8 and 9 can be expressed on various scales, in accordance with principles discussed in Section IV. For example, the spectral analytical densities of the magenta deposits at 535 mμ are 0.76 and 1.52, respectively. The more conventional scale is that of "equivalent neutral densities." These have been so defined that the yellow, magenta and cyan deposits shown in Fig. 8 each have an equivalent neutral density of 1.00 (since their superimposed absorptions constitute a visual gray of that density). It follows for this particular set of three dyes, and for this set only, that a yellow deposit of equivalent neutral density 1.00 has a spectral density of 0.66 at 445 mμ. The yellow deposit shown in Fig. 9 has an equivalent neutral density of 2.00, and a spectral density of $2 \cdot 0.66 = 1.32$. In general, a yellow deposit of equivalent neutral density Y will have, at 445 mμ, a spectral density of $0.66 \cdot Y$. Analogous relations apply to the other two dyes, and to other wavelengths.

Integral Densities from Equivalent Neutral Densities

Once the equivalent neutral density is known of each component in a composite specimen of the product illustrated in Fig. 8, it becomes a simple matter to obtain the integral density curve from the data represented by Fig. 8. It entails merely multiplying the ordinates of the spectral density curve of each component, as shown in Fig. 8, by its respective equivalent neutral density, and plotting the summation of the resulting densities at each wavelength. To give an example, let the equivalent neutral densities of a composite sample of this process be 2.00, 1.50 and 1.10 for the yellow, magenta and cyan, respectively. Then at 445 mμ, the density of the yellow component would be $0.66 \cdot Y = 0.66 \cdot 2 = 1.32$; that of the magenta component would be $0.24 \cdot M = 0.24 \cdot 1.50 = 0.36$; and that of the cyan component would be $0.16 \cdot C$

$= 0.16 \cdot 1.10 = 0.18$. The integral spectral density at 445 mμ would therefore be:

$$D_{445} = 0.66Y + 0.24M + 0.16C = 1.86.$$

The corresponding relations at 535 mμ and 660 mμ are:

$$D_{535} = 0.09Y + 0.76M + 0.17C = 1.51.$$
$$D_{660} = 0.04Y + 0.05M + 0.84C = 1.08.$$

In a similar manner, the integral densities at all other wavelengths in the spectrum may be calculated; the result is shown in Fig. 10.

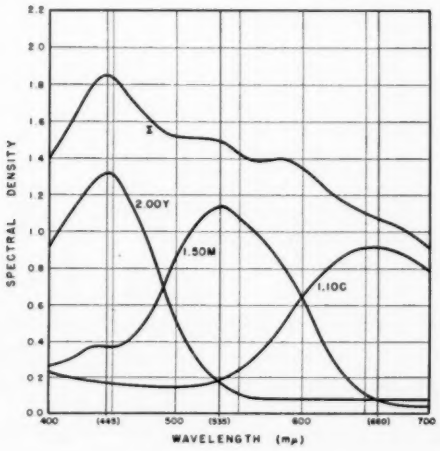

Fig. 10. Spectral densities of a non-gray image (Σ) formed by varying the amounts of the dyes in the gray image of Fig. 8. The equivalent neutral densities of this image are 2.00 (yellow), 1.50 (magenta) and 1.10 (cyan).

An integral color densitometer reading the spectral densities of the composite sample at wavelengths 445 mμ, 535 mμ and 660 mμ would indicate the densities shown in the equations just cited. If, for simplicity these are designated as "blue", "green" and "red" densities D_b, D_g, and D_r, the final relations for computing integral spectral densities from equivalent neutral densities are, for this particular dye system and these particular wavelengths:

$$D_B = 0.66Y + 0.24M + 0.16C,$$
$$D_G = 0.09Y + 0.76M + 0.17C,$$
$$D_R = 0.04Y + 0.05M + 0.84C.$$

Equivalent Neutral Densities from Integral Densities

The reverse procedure is not as simple, but it is nevertheless straightforward. In order to obtain the equivalent neutral density of

each component in a composite specimen from integral density measurements, the integral density of the sample must be determined at three different wavelengths, preferably in the region near maximum absorption of each component.

It is assumed that data corresponding to those shown in Table II are available for the dye system in question; these basic constants are the spectral densities, at the three wavelengths of the integral densitometer, of single dye deposits of equivalent neutral density 1.00. Let b_y, g_y and r_y designate the blue, green, and red densities of the unit yellow deposit, with corresponding abbreviations for the magenta and cyan constants.

The conversion equations derived in the preceding sections can then be written in the more general form:

$$\begin{aligned} D_B &= b_y\, Y + b_m\, M + b_c\, C \\ D_G &= g_y\, Y + g_m\, M + g_c\, C \\ D_R &= r_y\, Y + r_m\, M + r_c\, C. \end{aligned}$$

This system of three simultaneous equations may be solved for the three unknowns Y, M, and C, by ordinary algebraic procedures.[24] The solution is:

$$\begin{aligned} Y &= a_{11}\, D_B + a_{12}\, D_G + a_{13}\, D_R \\ M &= a_{21}\, D_B + a_{22}\, D_G + a_{23}\, D_R \\ C &= a_{31}\, D_B + a_{32}\, D_G + a_{33}\, D_R. \end{aligned}$$

The nine new constants are:

$$a_{11} = \frac{1}{N}\,(g_c\, r_m - g_m\, r_c);\ a_{12} = \frac{1}{N}\,(b_m\, r_c - b_c\, r_m);\ a_{13} = \frac{1}{N}\,(b_c\, g_m - b_m\, g_c);$$

$$a_{21} = \frac{1}{N}\,(g_y\, r_c - g_c\, r_y);\ a_{22} = \frac{1}{N}\,(b_c\, r_y - b_y\, r_c);\ a_{23} = \frac{1}{N}\,(b_y\, g_c - b_c\, g_y);$$

$$a_{31} = \frac{1}{N}\,(g_m\, r_y - g_y\, r_m);\ a_{32} = \frac{1}{N}\,(b_y\, r_m - b_m\, r_y);\ a_{33} = \frac{1}{N}\,(b_m\, g_y - b_y\, g_m),$$

where

$$N = b_y\, g_c\, r_m + b_m\, g_y\, r_c + b_c\, g_m\, r_y - b_y\, g_m\, r_c - b_m\, g_c\, r_y - b_c\, g_y\, r_m.$$

This operation can be stated more concisely in the notation of matrix algebra, where the nine coefficients are simply elements of a transformation matrix. We are here primarily interested in the fact that the previous equations can be solved to provide a simple system for the calculation of equivalent neutral densities from measurement of integral spectral density. For the dye system of Fig. 8, the transformation equations are:

$$\begin{aligned} Y &= 1.59\,D_B - 0.50\,D_G - 0.20\,D_R \\ M &= -0.17\,D_B + 1.39\,D_G - 0.25\,D_R \\ C &= -0.07\,D_B - 0.06\,D_G + 1.22\,D_R. \end{aligned}$$

To illustrate the use of these equations, we consider the sample of Fig. 10. An integral densitometer reading spectral densities at 445, 535 and 660 mμ would indicate for this sample the values plotted in the top curve; $D_B = 1.86$, $D_G = 1.50$ and $D_R = 1.07$. Substitution of these numbers into the equations above yields the correct answers: $Y = 2.00$, $M = 1.50$, and $C = 1.10$.

Non-monochromatic Integral Densities

Throughout this treatment, it has been assumed that the integral densities have been determined on instruments reading monochromatic spectral densities. Most practical instruments achieve only an approximation of this condition; even where a special effort is made to use narrow-band filters, the bandwidth is often more than twenty millimicrons. For such instruments, the transformation coefficients b_y, b_m, etc., are no longer the spectral densities of Table II, but rather the corresponding density readings actually obtained on the instrument for single dye deposits of equivalent neutral density 1.00. However, the validity of transformation equations derived in this manner becomes more and more questionable as the filter bands widen. These linear equations were based on the principle that the individual densities of superimposed dye deposits could be simply added to give the integral density of the combination, and this is not valid for integral densities obtained with wide filters. In the best narrow-band instruments, the departures are relatively small; whether they are within tolerable limits depends on the application. In any given situation, the calculated analytical densities should be compared with known values for a series of samples which cover the range of densities and colors over which the calculations are to be applied.

Modified Conversion Equations

A second complication arises from the fact that the absorption of radiant energy in an actual film sample cannot be entirely accounted for by the absorption of the yellow, magenta and cyan dye images. Additional radiation losses occur in the film base and in non-image "stain" as well as by reflection. To a first approximation, errors from these losses can be corrected by the addition of small constant terms to the transformation equations, which then assume the form:

$$\begin{aligned} Y &= a_{11} D_B + a_{12} D_G + a_{13} D_R + a_{14}, \\ M &= a_{21} D_B + a_{22} D_G + a_{23} D_R + a_{24}, \\ C &= a_{31} D_B + a_{32} D_G + a_{33} D_R + a_{34}. \end{aligned}$$

The values of these constant terms can be determined by trial. Since the equivalent neutral densities of gray samples are equal to their luminous densities, gray samples offer an accurate means of trial. Their measured densities are compared with their computed equivalent neutral density values. The computation equations are then altered by addition of the constants required to minimize errors. This empirical method of determining the additive constants a_{14}, a_{24} and a_{34} also provides a first-order correction for the departures shown by actual materials from the theoretical relationships discussed under *Density as a Function of Dye Concentration*, above.

Further improvement in the calculation of analytical densities might be achieved by the use of nonlinear transformations, but the added computing burden would make it difficult for such a procedure to compete in utility with the direct measurement of analytical densities.

Computing Devices

The large-scale use of computed analytical densities in color sensitometry is dependent on rapid and economical procedures for the solution of the linear transformation equations which have been discussed. Standard desk calculators with provision for accumulative multiplication are well suited to this task. Alternatively, it is possible to use electrical networks for the solution of these equations. In the latter type of instrument, the values of D_R, D_G and D_B are put in as shaft rotations, and this operation could, in principle, be directly performed by the integral densitometer in cases where the integral densities themselves are of no interest. In situations where only few data are to be handled and the required precision is not high, nomographs may be used to advantage.

VII. INTERPRETATION OF SENSITOMETRIC RESULTS

The primary results of the ordinary procedures of color sensitometry are sets of color density values that describe the images produced by known exposures. These color densities vary with changes in film, with processing changes, and with many other factors which must be evaluated and controlled in the practice of color photography. The interpretation of the results in terms of these many factors is the final step in color sensitometry.

This step, like all interpretation of technical data, will be governed by the specific purpose at hand. In research and development work leading to new materials and processes, the results of sensitometry are used in studying the effects of manufacturing and processing changes on fundamental characteristics such as speed, gradation, latitude, color reproduction and keeping properties. The present report will not attempt to deal with this wide range of problems which are of interest to only a small group of research and manufacturing establishments.

In the domain of the motion picture laboratory, the range of problems is narrower, but the role of color sensitometry is no less important. The adjustment and control of processing and printing operations require long-range as well as day-to-day decisions which must be based on the results of sensitometric tests. These are the purposes with which the present discussion of data interpretation will be primarily concerned.

Since this subject involves purposes as well as facts, it is inherently more controversial than the material in previous sections. The principles here discussed are tentative; their validity can be established only as more experience accumulates in this relatively young field.

Process Adjustment

Successful operation of a color film process is usually accomplished in two stages. In the initial period of operation, the process is intentionally changed after each trial run until the results are judged satisfactory. Once the aim point has been established, the objective will be to produce results repeatedly with minimum departure from

this aim. The first stage will be called *adjustment,* and the second *control.*

Adjustment of the process normally calls for evaluation as discussed in Section I. It will be the function of color sensitometry to provide an objective description of process performance. This calls for interpretation of the results in terms of the application for which the film is intended. If the film is a positive intended for screen viewing, the sensitometric results must be interpreted in terms of visual appearance; if, on the other hand, the film is a camera original or an intermediate negative or positive, the evaluation must be made in terms of printing characteristics.

Evaluation for Viewing

A print process yielding positives for screen projection will generally be adjusted by considering the over-all quality of the reproduction. The objective will be to produce a pleasing likeness of the original scene; if the camera original has certain systematic defects, the print process will be adjusted, wherever possible, to compensate for them. Subjective quality judgments of representative scenes will be an essential factor in this adjustment; the corresponding sensitometric data will show final print densities as functions of exposure of the camera original. For this purpose, a camera film carrying a sensitometric image will be printed on the print film by the normal printing procedure.

Such "over-all" reproduction data are the primary measurements in adjustment. They are often supplemented by direct print film sensitometry, in which print densities are studied as a function of print exposure, independent of the camera film. These separate measurements on the print process can be made with somewhat higher precision than the over-all measurements. In some cases, the aim point for the adjustment of a print process is already known in terms of direct print sensitometry; the actual adjustment can then be made by print sensitometry without recourse to over-all measurements or picture quality judgments. In other cases, clues to specific print process changes may be more apparent in direct print sensitometry than in over-all measurements. But wherever the aim point is in question it is sound procedure to return to the primary method of evaluating, by measurement and by subjective judgment, the over-all quality of the reproduction.

Gray Scale Exposures

Two basic requirements are often stated in discussing the "over-all" rendition of color processes: A gray tone scale in the original scene must be rendered as a visually gray tone scale in the finished image, and the image tone scale must reproduce the contrast of the original scene. Both criteria are open to qualification in specific processes. In some processes, optimum picture quality, as established by careful judgments with many observers, is achieved under conditions that do not reproduce a gray scale as a series of visual grays. Similarly, the imperfections of many color processes are such that a more pleasing picture is obtained when the over-all contrast is increased above unity. In such cases, the saturation of the colors in the reproduction will be more nearly correct, but the contrast in the gray scale will be excessive. If these limitations are kept in mind, the original requirements may still serve as a useful guide for the initial adjustment of a print process. They can be combined into a single rule: *A gray scale in the original scene should be reproduced as a similar gray scale in the final image, both with respect to color balance and contrast.*

While no process can be successful if it departs very far from this condition, it must be realized that this is by no means a *sufficient* condition for satisfactory reproduction, and that non-gray exposures must be used to supplement the usual gray scale sensitometry.

In a process in which gray subjects are reproduced as approximately gray images, the contrast, density range, and similar reproduction characteristics of the gray scale can be interpreted by the methods of black-and-white sensitometry. For this purpose, the gray or nearly gray images should be read on an integral densitometer which reads luminous densities (see Section IV). Such a densitometer will yield results in agreement with the brightness evaluations that would be made by a normal observer in a visual densitometer. To obtain the over-all reproduction characteristics, these print densities must be plotted against the logarithms of the sensitometer exposures that were given to the camera film.

While the individual steps of the gray scale reproduction in the print may be sufficiently close to a visual gray to permit over-all evaluation by luminous densities, the color of each step usually departs from gray, and the magnitude and direction of these departures are important characteristics of the process. In fact, the adjustment of these differences is one of the major tasks of process adjustment.

Integral Color Densities

Three density values are necessary to describe the color of each image, and for images that are to be viewed on the screen these densities should, in principle, be the colorimetric densities described in Section IV. These are the only densities directly related to the international standard scales on which the color of the images would be correctly described. In practice, however, it has been found sufficient to demand that the density numbers used for this purpose should satisfy these simpler requirements: (a) The three densities describing a gray image should be equal, and (b) in describing a nongray image, the differences among three unequal densities should give an approximate indication of its hue and saturation.

Arbitrary three-filter integral densities will not satisfy the first of these requirements; neither will spectral densities. For an accurately gray image in a typical process, Fig. 8 shows spectral densities of 1.06, 1.01 and 0.93. For a given process, it would be possible, of course, to select reading wavelengths such that equal densities would correspond to a gray at least at one density level. Alternatively, it would be possible to compute, for other wavelengths, multiplicative scale factors which would so convert the original densities that equal numbers would correspond to a gray at least at one density level. In direct-reading densitometers, this multiplication might be automatically performed in the indicating circuit. However, either scheme can be expected to work over a large density range only if the original integral densities are approximately monochromatic. Even then, the correction would be imperfect, although the resulting numbers might be useful in many applications. The principal reason for disregarding this possibility has been the interest in analytical density scales, which involve additional objectives in a somewhat different direction.

Before discussing these additional features, the second of our requirements must be briefly considered. Since an image on the film is uniquely specified by any three integral densities, it follows that it must be possible to infer the color of the image from the three density numbers. However, it has been the intent of our requirement that the correlation between these numbers and the color of the image should be easy to visualize and remember. This is not the case in the systems considered in the preceding paragraph. Figure 11 shows a conventional integral density plot in which narrow-band filter densi-

ties for a hypothetical print are plotted against the logarithms of camera exposure. While it is possible to guess that the highlights will be reddish, the middle densities bluish and the shadows green, it is difficult to go beyond these meager and uncertain statements. Considerable experience is necessary before density numbers can be reliably interpreted as approximate image colors. The practice of

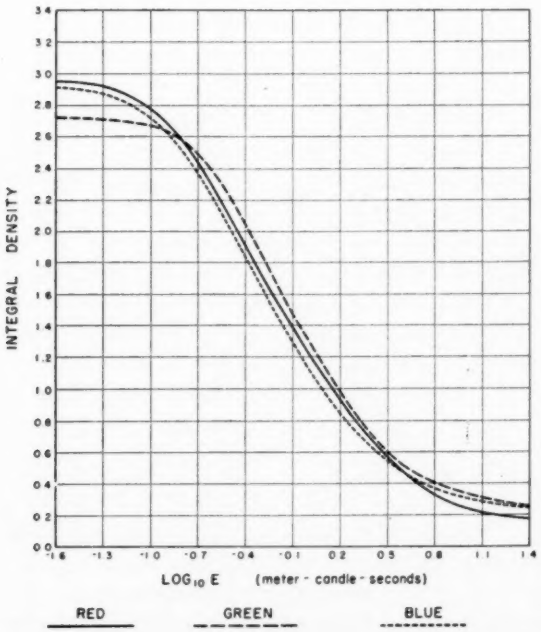

Fig. 11. Integral density plot of the over-all characteristic curves of a hypothetical process. Red, green and blue narrow-band filter densities are plotted against the logarithms of exposure. The relative positions of the curves suggest reddish highlights, bluish middle tones and green shadows.

estimating color by color density differences is fairly common, and often includes the plotting of such differences on trilinear co-ordinate graphs. The danger of this practice lies in the circumstance that the correlation between image color and density differences is different at different levels of absolute density. A given set of density differences in two images of different absolute density levels does not guarantee

that the images have the same color. Experience in the interpretation of density difference data must therefore be separately acquired for each density level.

It has been suggested that, in the absence of such experience, the relationship between image color and densitometer readings can be determined and catalogued. If this relationship does not shift with normal variations in processing or emulsion composition, it is possible

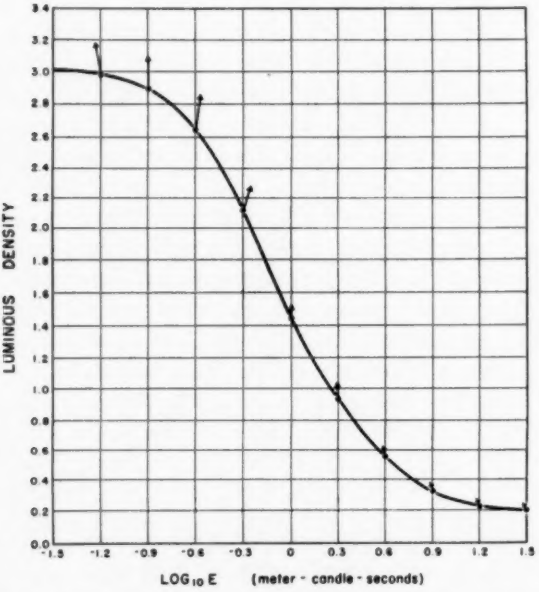

Fig. 12. Gray-scale reproduction characteristics of a color process. Luminous densities of approximately gray images are plotted against the logarithms of exposure. For each step, a small vector is shown; its direction is related to the hue, and its length to the saturation of the image. A zero vector would indicate an accurately gray image.

to construct tables or graphs by means of which a set of three integral densities may be translated into luminous density and two numbers associated with hue and saturation.

These numbers can be represented by a point on an ICI chromaticity diagram,[11] and a vector can be drawn to this point from the point which represents zero densities. A small-scale replica of this vector can then be drawn on the luminous density plot (see Fig. 12); for each

step, this small vector is drawn from the point representing that step on the H&D curve. The direction of the vector is related to the hue of the sample, the length to its saturation. Where there are available densitometers which measure colorimetric densities directly, this method of presentation is relatively straightforward. If integral spectral densitometry is used, the construction of the necessary empirically derived tables and graphs and their interpolation are relatively complex.

Analytical Color Densities

In problems connected with the manufacture and improvement of color film and color processes, it is frequently important to study images in terms of the individual amounts of the dyes. As outlined in Section IV, a description of the image in these terms is provided by analytical densities. If the scales of analytical densitometers are calibrated to yield equivalent neutral densities, or if the latter are obtained by calculation (see Section VI), one of our former requirements is automatically satisfied: Visual grays are specified by three equal density numbers. Whether the requirement for easy visualization of image color is better met by equivalent neutral densities than integral densities is controversial; neither system is very good in this respect.

The important advantage claimed for analytical densities is in a somewhat different direction. In the adjustment of the process for optimum results, it may be possible to perform changes which affect the formation of only one of the three dyes. For example, in a process involving separate color developers, the contrast of one of the dye images may be varied independently of the other two. If the magenta contrast is increased in the process illustrated in Fig. 5, the magenta curve will follow a steeper course, while the other curves will remain unchanged. This direct interaction between a variable that can be manipulated and a simple change on a sensitometric graph is of great value. Had integral densities been used in the case under discussion, the green curve would have become substantially steeper, but the blue curve would also have become somewhat steeper. With two or more simultaneous process changes of this type, the effects may be very difficult to isolate on integral density graphs.

On the other hand, the assumption of independent process variables operating on only one dye is somewhat idealized, and the usefulness of analytical densities can be more eloquently argued for a manufac-

turing establishment than a processing laboratory. For the latter, the use of equivalent neutral densities will be justified if their plot gives a clearer picture than the integral density plot of the effects of the processing variables that can be adjusted. The decision must be based on experience with a particular process. Once the choice has been made it is not easily changed, because the interpretive experience gathered by the sensitometric staff cannot be transferred.

Non-Gray Exposures

The importance of supplementing the usual gray scale sensitometry with the study of non-gray exposures has already been stressed. To determine the fidelity of reproduction of chromatic exposures (filters in the sensitometer, or test charts before the camera), visual judgments may be supplemented by colorimetric comparisons. It must be borne in mind that the accurate reproduction of highly saturated colors is beyond the capability of current three-layer subtractive processes. Standard methods for the interpretation of colored sensitometric images have not been formulated. In most laboratories, reference color densities for non-gray test patch images will be empirically established, and the actual densities obtained during process adjustment will be evaluated with respect to these reference densities.

Evaluation for Printing

In professional motion picture practice, the essential features of a camera original are contained in its printing densities. Printing densities describe how the original record of the scene will control the next step of the photographic process. This next step will be the printing either of the final positive or of an intermediate film. In either case the camera original is essentially only a means by which the point-to-point exposure made in the camera by the scene image can control the point-to-point exposures of the final positive print.

In considering evaluation for viewing, it was pointed out that "if the camera original has certain systematic defects, the print process will be adjusted, wherever possible, to compensate for them." It is equally true that whatever the systematic characteristics of the print material, the camera original or printing operation must be adjusted to best utilize them. In either event, essential knowledge can be derived from characteristic curves of the camera original material, plotted in printing densities.

A typical set of printing density curves for a color negative material has already been shown in Fig. 1. In evaluating such curves the three members of the set must be considered both individually and as a group.

The interpretation of the individual curves is but little different from the interpretation of a characteristic curve of a black-and-white negative material. Each curve represents, in fact, a negative which will control the printing of one of the components of a positive material. The "speed" of the negative can be determined by a gradient method[25] or a fixed-density method, just as in black-and-white sensitometry. Methods in use vary with the product and with the individual sensitometrist. Any method must meet two requirements:

(1) Variations from sample to sample in the "speed" thus determined should directly measure the required or permissible variations in camera exposure of the product.

(2) Disagreement among the "speed" values from the three curves of the negative material should correlate well with any changes of camera lens filter or illuminant quality required to make best normal use of the product sample. Measurements made in the toe portions of the negative curves have generally been found most satisfactory for these purposes.

The absolute density values of the individual curves are, in principle, much less important than the density relationships. The over-all density of a negative curve determines the amount of printing light required to print it; as long as the printer intensities can be made sufficiently high to permit printer operation at economical film speeds, it matters little what the absolute density levels are. Even the variations encountered (from product to product and sample to sample) in the *differences* in over-all density level of the separate printing density curves of negative materials can be offset by changes in printer setup. Of the qualities in the negative that can be shown by a gray scale test, the really important ones are those that are dependent on the curve gradients.

In black-and-white sensitometry, the most familiar expression of gradient is *gamma*, the slope of the straight-line portion of the sensitometric curve. In color photography the curves so rarely have straight-line portions that the term "gamma" is seldom used. It is replaced by average gradient, sometimes called *contrast*, although the term is rather ambiguous. *Average gradient* is measured by either of two methods: (a) by selecting a minimum and a maximum value of log E

which together define a region of particular interest, and determining the slope of the straight line joining the points on the characteristic curve corresponding to these exposures, or (b) by selecting a minimum and a maximum density which define a density region of particular interest, and determining the slope of the straight line joining the points on the characteristic curve at which these density values occur. The exposure or density intervals may be intended to encompass the entire useful exposure or density range of the negative, or more frequently only a part of it, such as the highlight, or middletone, or shoulder portions.

Many print materials are designed to operate best with negatives equivalent to an equal-contrast set of separation negatives. For these print materials, the color negatives are presumably best when their printing-density curves can be made congruent simply by overall density adjustment. This requires that along all possible vertical lines within the usable range of exposure, the three negative curves must show constant separation. This condition is not met by the curves of Fig. 1. Among other defects of the represented material are too low a gradient in the low-density region of the green-density curve, too low a gradient in the shoulder region of the same curve, and too high a gradient in the shoulder portion of the blue-density curve. The effects of mismatch between blue and red speeds are shown in the lack of constant separation between their toe portions. This mismatch is normally assumed to be undesirable. It is true that, particularly in professional work, no such assumption is safe, since the best characteristics of the negative are those which best fit the positive material, but it is equally true that negative-positive adjustments that compensate for each other's deficiencies in a complex manner, are useful only under uncomfortably limited conditions of exposure and processing.

Process Control

The primary task of process adjustment ends at the point where it is decided that the results will be acceptable without further modification. After this point, the manipulation of the process becomes a problem of *control*, with the objective of minimizing all departures from the reference results. Successful process control requires, first of all, that the process conditions known to produce satisfactory results are specified as completely as possible in terms of all the variables to which the picture results are sensitive. This includes the concentra-

tions of active solution constituents as well as physical parameters such as temperatures and flow rates. The identification of the critical variables is one of the major problems of process research, and much work remains to be done in this field.

While the primary method of control is continuous adjustment of these variables to the standard values, a final check is generally maintained by sensitometric procedures. Here again, the results are compared with reference values obtained under conditions known to produce satisfactory results. Such reference values are usually given as density values for definite test exposures. The choice of the particular exposures and the specification of the type of density will be governed by individual circumstances.

At first sight, the task seems very much simpler, since the objective is only to duplicate previously obtained density values. Any system of color sensitometry will serve to detect whether an earlier result is or is not repeated. In actual practice, exact repetition is only achieved in exceptional cases; usually the tests exhibit small departures from the aim. Frequently, an attempt is made to utilize measurements of this difference as indications of corrective measures. Whether this is sound procedure or not is controversial; many process operators believe that primary measurements of the process variables provide more sensitive and more reliable guidance. Where sensitometric indications are used, data should be selected that are closely related to process variables that can be manipulated. Generally, this will mean controlled exposures made directly on the print film, in place of the printer exposures made from negative images (as discussed under *Evaluation for Viewing* above). Detailed control studies are necessary to be sure whether integral or analytical densities are preferable; where the answer is uncertain, the decision will often be in favor of the method for which adequate instruments are available.

Printer Adjustment and Control

The use of sensitometry in printer adjustment and control is in many ways similar to its use in process adjustment and control. Sensitometric calibration of the available variables is equally important in the two cases, but easier in the case of printer operation than in process operation. In both cases sensitometric specification of proper conditions must be established, and in both cases departure from proper condition must be expressed in terms easily related to the calibration of the available variables.

The known methods of color sensitometry do not provide exact objective specification of the best possible printing of a color negative or positive. Picture judgments are required to specify the final printing adjustments. But sensitometry has these important functions in printer operation:

(1) Specification of printer conditions required for a given negative to a precision sufficient to provide first approximations from which further corrections can be confidently predicted by picture judgments.

(2) Specification of printer changes to minimize differences among print film stocks.

(3) Specification of printer changes to produce a known desired effect.

The efficient use of sensitometry in these functions requires establishment of correlations between printer changes and negative characteristics (assuming a negative-positive process), and between printer changes and print-image characteristics. Theory suggests that the correlations will be most direct when printing densities are used for the former, and equivalent neutral densities for the latter.

Most of the sensitometry involved in *printer adjustment* will make use of a camera-exposed image of a gray scale on the negative material to be printed. For initial adjustment, it may be assumed that this scale is to be reproduced as gray (at least in its middle tones). A trial print which is not gray can yield sensitometric information adequate for approximate correction. The separations of the equivalent neutral density curves of the reproduction define the corrections to be made in the relative exposures of the red-, green- and blue-sensitized components. They will also show what step of the negative gray scale is being reproduced at the density which is assumed correct for reproduction of white. Printing densities of the negative gray scale will reveal the differences between the densities of this step and of the step corresponding to white. The printer is to be adjusted in accordance with these differences. These adjustments, or possibly a second round of them, will set the printer well enough to make a series of trial picture prints.

When the best possible picture print has been made and chosen, a record can be made of the sensitometric characteristics of the corresponding gray scale. This correlation, corrected and extended by subsequent experience, will serve as a practical guide in making trial prints based on printing density measurements of other camera-ex-

posed negatives, representing other scenes and possibly other negative materials.

Where direct photometric measurements are unobtainable, *printer control* can be exercised by comparisons of prints resulting from printer exposures made through a standard sensitometric-scale negative with prints, simultaneously processed, resulting from sensitometer exposures; that is, the printer is controlled by reference to an unchanging sensitometer, using the print material as the comparison medium. Ideally, this comparison should be made by use of analytical densities of the resulting prints, but the comparison should be made using images so nearly identical that any three-filter densitometry should suffice.

The effects of change of print film stock can be evaluated in several ways; analytical densities, preferably equivalent neutral densities, give the information most directly related to the changes in printer adjustments which can be made to minimize the differences. The analytical density curves permit the direct determination, with reasonably good accuracy of the required changes in the individual layer exposures. If the printer adjustments cannot change these exposures individually, it is possible to set up a quantitative calibration by a procedure similar to the transformation of integral to analytical densities.

Sound Track Evaluation

The evaluation of sensitometric tests for sound records on color film follows the same principles that have been considered for picture records, although the actual procedures are different. The quality judgments that are obtained for the picture area by screen viewing and by colorimetric measurements have their sound track counterparts in listening tests and in electrical measurements.[26] The adjustment of sound track printing and processing is governed by tests of sound quality (e.g., measurements of signal-to-noise ratio and intermodulation tests). Until the conditions for optimum reproduction have been established, sensitometric procedures are restricted to a secondary role. Once the optimum conditions are known, they can be correlated with sensitometric measurements which may then become the primary means of control. At that stage, the problem of interpretation becomes one of comparing the sensitometric characteristics of a given test with reference data.

The density values used for such comparisons must correspond to the action of the sound track image in the sound reproducer. An integral density measured in a narrow region of the visible spectrum may be a completely misleading indication of image performance in a sound system using customary photocells with cesium oxide or S-1 surfaces. The maximum sensitivity of these photocells lies in the infrared region near 800 mμ, where most dye images are quite transparent. A quite different spectral sensitivity with a maximum near 400 mμ is obtained in photocells with S-4 surfaces; such cells have been successfully used[27] in experiments with dye sound tracks. In the 16-mm field, lead sulfide cells[28] with maximum sensitivities in the range from 1000 to 3000 mμ have recently come into some use. The SMPE Color Committee voted in October, 1949, to ask the color film manufacturers to determine which of these phototubes are best suited for reproducing sound recorded on their particular color products. Meanwhile, the interpretation of sound track sensitometric tests should be based on integral densities that accurately represent the spectral response characteristics of the particular type of sound reproducer with which the film is to be used. This will normally require a densitometer equipped with a photocell of the same type as that used in the reproducer.

VIII. STATISTICAL ASPECTS OF COLOR SENSITOMETRY

The nature of sensitometric measurements and the materials on which they are made give rise to random variations in the results. In the presence of these random variations precise determinations are not possible on the basis of a single experiment. Reliable conclusions can be drawn, however, from multiple experiments interpreted by statistical methods. Experienced operators have long realized the distinction between significant and insignificant differences in results, but the quantitative study of these variations and of their bearing on control problems is a relatively recent development. Within the limits of the present report, these methods cannot be fully described nor even adequately outlined; the purpose of this final section is simply to call attention to the existence of this new and important phase of color sensitometry.

Statistical Variation of Results

When several duplicate exposures are made on a small sample of photographic material, and the group is processed together under carefully controlled conditions, and then measured on a correctly adjusted densitometer, the individual images will not have identical densities. If the sensitometric test procedure is well controlled, these density variations will represent random variations for which no specific causes can be assigned.

Variations greater than these random variations, for which assignable causes can be found, will often be observed when (a) different coatings of photographic material are tested, (b) the material is exposed on different sensitometers or on the same sensitometer at different times, (c) the strips are processed at different times, and (d) the processed strips are read on different densitometers or on the same densitometer at different times. An important problem of color sensitometry is the evaluation of such systematic differences from data which contain the random variations.

Individual Sources of Variation

Among these different components of systematic variability the only one that can be isolated for independent study is the densitometric variation. Its magnitude can be determined by measuring the same processed sensitometric strip on several densitometers, or on the same densitometer at various times. An objective of good densitometer design and of sound maintenance and control procedures is the

reduction of this particular source of variation to the minimum value that is economically practical.

Variations in sensitometric exposure cannot be isolated on finished sensitometric strips, but photometric methods can be used to arrive at an independent check on the magnitude of such variations.

On the other hand, there is no completely satisfactory procedure by which variations in film or processing can be independently studied. The difficulties of separating these two factors have already been considered in Section III. The best that can be done is to study one of the components of variation under conditions that make the remaining components relatively small. For example, a single test of film variability can be made by exposing sensitometric strips as closely as possible at the same time on a carefully controlled sensitometer, and then processing all of the strips in random sequence at the same time. Where repeated tests of this kind are required, it will be desirable to keep process variations small, because differences in film characteristics vary with process changes.

Multiple Factor Experiments

Statistical methods[29] are available for the treatment of more complicated experiments in which two or more factors are separated and evaluated in the same group of experiments. However, in applying such methods to problems involving film and processing variations, one must be sure to exclude assignable causes of variation resulting from "keeping" changes in the film during the intervals between manufacture and exposure and between exposure and processing. This is very difficult in practice, and multiple factor experiments have therefore been little used in color sensitometry.

As an illustration of a somewhat different use of such multiple factor experiments, consider the problem of maintaining two or more densitometers so that six different test operators will be able to obtain essentially the same densitometric measurements on all parts of the scale of a sensitometric strip. Each test operator would be asked to make density measurements on several sensitometric strips using both densitometers. The resulting data could be studied by variance analysis[29] to see whether significant differences existed between the results from Operator A and Operator D, or between Densitometer No. 1 and Densitometer No. 2.

Statistical Methods of Data Presentation

Statistical methods are most efficient when used to help interpret the results of experiments which have been properly designed. Several

simple statistical methods can be used to present data and interpret experimental results in color sensitometry. It should be emphasized that no method of summarizing and presenting experimental data should ever lead the reader to draw different inferences than he would have drawn (more laboriously) by references to the original test results.

Frequency Diagrams

Frequency diagrams[30] (histograms) can be recommended for studying the results of large experiments when the order in which the experimental work was done is not of great importance. They are usually preferable to tables because they immediately convey a graphic picture. Figure 13 shows a frequency diagram for the sensitometric tests made on samples of film made during an arbitrary test run. The information shown in this graph is equivalent to that contained in Table III. The shape of such histograms gives important information about how well the process was controlled during the period under study. Well controlled systems usually produce single-

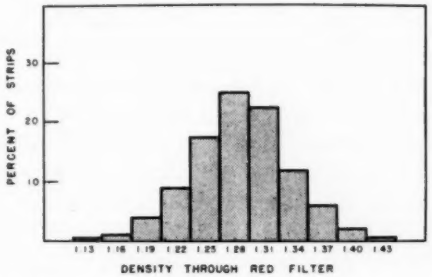

Fig. 13. Frequency diagram (histogram) for the red densities of 462 images obtained during an arbitrary test run.

Table III. Densities Through Red Filters During an Arbitrary Test Run

Densities	Number of strips	Percentage of strips	Densities	Number of strips	Percentage of strips
1.12 to 1.14	2	0.4	1.30 to 1.32	104	22.5
1.15 to 1.17	5	1.1	1.33 to 1.35	55	11.9
1.18 to 1.20	18	3.9	1.36 to 1.38	28	6.1
1.21 to 1.23	41	8.9	1.39 to 1.41	9	1.9
1.24 to 1.26	81	17.5	1.42 to 1.44	3	0.6
1.27 to 1.29	116	25.1			
			Total	462	99.9

peaked distributions which are symmetrical. A narrow tall distribution indicates a more uniform product than a wide shallow distribution.

Control Charts

The order or time sequence in which a set of experimental results was obtained can be shown by presenting data in the form of a con-

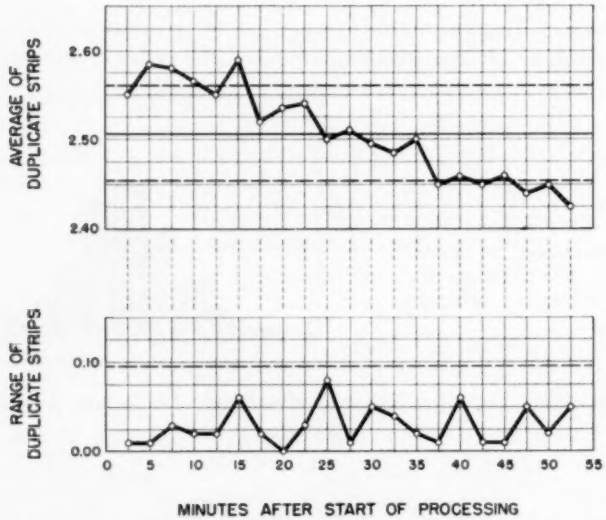

Fig. 14. Statistical control chart for a one-hour run of an experimental process. Duplicate strips were run at 2½-min intervals, and the blue densities were read for one image on each strip. The lower chart shows the density differences between duplicate strips. The upper chart shows the average density of duplicate strips. The downward trend shown on the upper graph exceeds the control limits calculated from the results shown in the lower graph.

trol chart.[30] The experimental work should be designed so that the results can be arranged logically into rational subgroups. These rational subgroups can be chosen within test machines, within test operators, within arbitrary units of material, within stated periods of time, and in many other logical ways. The control chart compares the variability of the entire set of results with the variability within these rational subgroups.

Figure 14 shows a control chart for the results of processing dup-

licate sensitometric strips at 2½-min intervals for about one hour in a single processing machine. The present illustration is concerned only with the blue integral densities of one specific step on each strip. The rational subgroups, in this experiment, are the groups consisting of the two strips processed at the same time. The density difference between two such strips (the "range" of duplicate strips) is taken as a measure of the variability within each subgroup. The lower graph in Fig. 14 shows this quantity for each of the 21 subgroups. The dotted line on this lower graph indicates a statistical control limit based on the average range. Within the duration of this experiment, all ranges of duplicate strips are within the control limit; this is interpreted to mean that differences observed between duplicate strips processed together are due to nonassignable chance causes.

This minimum random variation also provides a basis for calculating the control limits shown by dotted lines in the upper graph of Fig. 14. Here, average densities of each set of two strips are plotted. As long as these average densities are within the control limits, the variations observed in the result may be considered as random effects from unassignable causes. The upper graph shows, however, that in the test under discussion the variations extend beyond the control limits. This is interpreted to mean that the downward trend shown during the hour may have had non-random origin. Such a situation would justify a careful search for specific causes of trouble.

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New 13.6-Mm Hitex Super High-Intensity Carbon

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Summary—**The new 13.6-mm Hitex super high-intensity carbon for operation at 170 to 180 amp in condenser-type lamps is described in comparison with the former 170-amp super. Data show that the Hitex super carbon gives the possibility of more light, more economical operation because of longer life and a marked improvement in efficiency of light production. Spectral energy and color data show that the light from the Hitex super has a higher color temperature than from the old super.**

THE TASK of providing adequate illumination on the largest screens used for the projection of motion pictures is one which has presented a continual challenge to the manufacturers of the equipment involved. Many large indoor theaters have never had as much light as was needed to obtain the results desired. The problem has been intensified in more recent years with the advent of many large-screen outdoor theaters which have much less light available on the screen than necessary to bring them up to the desired levels of screen brightness. The use of audience viewing areas several times larger than indoor theaters has necessitated the use of considerably larger screens. Projection screen areas are approximately four times as great for outdoor as for indoor theaters and consequently require four times as much light to achieve the same screen brightness. It cannot be definitely stated that outdoor theaters, with their different circumstances and surroundings, should have the same brightness as indoor theaters; but there is no doubt that most of them could effectively utilize much more light.

The condenser type of lamp employing rotating positive high-intensity and super high-intensity carbons is widely used by large screen theaters. The first step in the field of super high-intensity projection for large theaters came in 1936 when the 13.6-mm National super high-intensity carbon was introduced.[1] This carbon was designed for operation at 180 amp and produced more light more evenly distributed on the screen than carbons previously available. Further

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attention to the problem made it possible to introduce an improved 13.6-mm super carbon in 1941 for operation at 170 amp.[2] This carbon gave a 20% increase in light over the 1936 super with a 10-amp reduction in current and no increase in burning rate.

Continuing research and development work since 1941 has resulted in new methods of processing which make possible improved carbon compositions and properties. As a result, the new National Hitex super carbon has been introduced and reached new highs in the field of super high-intensity projection. It has brought greatly improved efficiency of light production and lower cost operation along with an increase in screen brightness.

OPERATING CHARACTERISTICS AND PERFORMANCE

The new Hitex super carbon is rated at 170 to 180 amp and has the burning characteristics shown in Table I. The light output on any

Table I. Characteristics of 13.6-Mm Old and New National Super High-Intensity Projector Carbons Under Typical Operating Conditions

	Old super	New Hitex super	
Arc amperes	170	170	180
Arc volts	75	70	74
Positive consumption rate (inches per hour)	24.0	16.0	21.5
Screens lumens at maximum light*	21,500	20,700	24,800
Side-to-center screen distribution ratio at maximum light	65	60	60
Screen lumens at 80% screen distribution†	18,500	17,500	19,300

*Screen lumens with no projector shutter, film or filters; condensers at *f*/2.0 adjusted for maximum light.

†Same as screen lumens at maximum light, except that condensers are adjusted for 80% side-to-center screen ratio.

given projection screen with these carbons will depend on a number of different factors. The influence of these various factors and the results obtained with typical projection systems were discussed in a recent paper.[3] Light measurements given in Table I have been made with the Hitex carbons on a typical condenser system in comparison with data previously obtained and published for the 13.6-mm super carbons[2] along with a description of the conditions under which they were obtained. With the optical system adjusted to produce maximum light on the projection screen, the Hitex super, at the lower end of its current range, approximately equals the light output of the old

super; and, at the upper end of its current range, it gives approximately 15% more measured light than the old super. At 80% side-to-center distribution ratio on the screen, the amount of light with the old super is intermediate between the values obtained from the Hitex super carbon at its two extremes of operating current. The Hitex super carbon, therefore, gives a certain flexibility, making possible, as it does, a range of light output running from a value at minimum operating current just below that of the old super upwards to one substantially higher at maximum operating current.

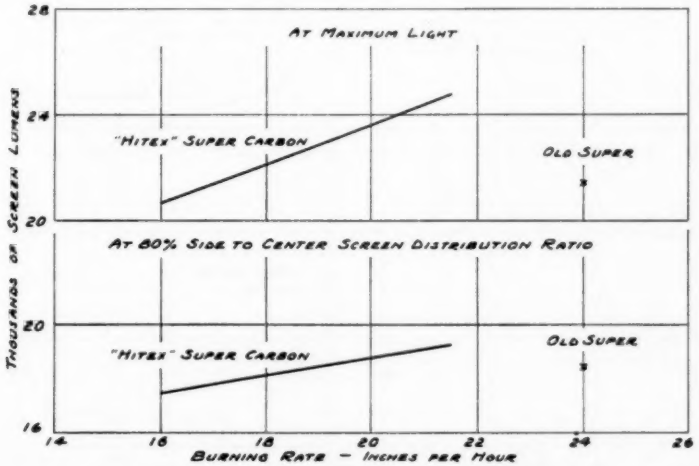

Fig. 1. Screen light with 13.6-mm super high-intensity carbons vs. burning rate, no film or shutter.

Figure 1 shows the data of Table I with the screen light plotted against the burning rate in inches per hour. Since carbon cost per hour depends on the burning rate, this method of plotting shows the amount of light at the various consumption rates and correspondingly different values of carbon cost per hour. Although the two carbons cover different burning rate ranges, it can be seen that the Hitex super carbon produces light much more economically than the old super. For example, at equal light output, the Hitex super carbon has about 30% to 40% longer life. The new carbon at 170 amp will project three double reels of 35-mm film per carbon compared to two double reels for the old super and therefore gives 50% longer burning life at

this current. At 180 amp, the Hitex super carbon will project two twenty minute reels and an additional short reel.

As is indicated by Table I and Fig. 1, higher light with a given optical setup is always accompanied by a higher carbon burning rate. The light output of a given carbon divided by its burning rate gives a measure of the total amount of light energy produced per inch of carbon consumed and measures the efficiency of conversion of the carbon into light energy. This efficiency is expressed in lumen-hours per inch and is plotted in Fig. 2 against the corresponding value of screen

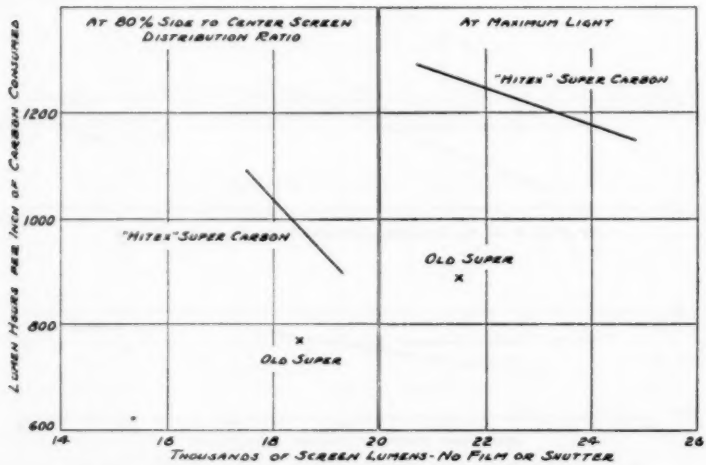

Fig. 2. Efficiency of conversion of carbon into light energy vs. amount of light produced.

lumens produced. This shows first that there is some decrease in efficiency upon going to the higher currents and higher amounts of light with a given carbon. Secondly, at corresponding amounts of light the Hitex super carbon has from 30% to almost 50% higher efficiency than the old super. Even at its highest current, where it produces more light than the old super, the Hitex still has approximately 15% to 30% higher efficiency.

The total amount of electric power consumed from the line will be proportional to the arc current with either a local, constant voltage d-c generator or a utility d-c power supply line; therefore, the amount

of light divided by the arc current, that is the lumens per ampere, is a figure which measures the efficiency of conversion of electric power into light. This measure of efficiency is plotted in Fig. 3 against the corresponding amount of screen light produced. This shows, first, that the efficiency of conversion of electric power into light increases as the current and the amount of light are increased. Secondly, Fig. 3 also shows that the Hitex super carbon has essentially the same power efficiency as the old super at corresponding amounts of light. This means that the advantages of the Hitex super carbon, such as its higher light, longer life and its greater efficiency of conversion of car-

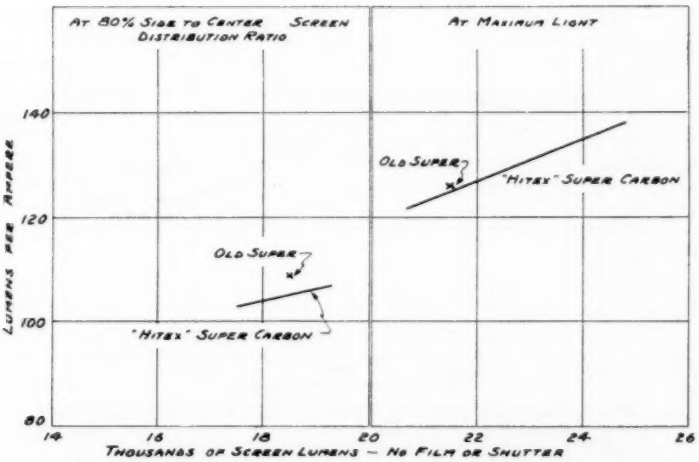

Fig. 3. Efficiency of conversion of electric power into light vs. amount of light produced.

bon into light energy, have all been achieved without any sacrifice of efficiency of utilization of power.

The light on the projection screen with the Hitex super carbon has a higher color temperature than with the old super. Comparison with the light from the old super on a blank screen without any film being projected, results in the appearance of a whiter light with the Hitex carbon. A spectral energy distribution curve of the light at maximum on the screen is given in Fig. 4 for the two carbons at 170 amp. The corresponding color temperatures are 5925 K (degrees Kelvin) for the old super and 6250 K for the Hitex super carbon.

Detailed measurements of total radiant energy falling on the film aperture have not yet been made with the Hitex super carbon by the method used in previous publications.[4] However, comparative measurements made with a new type of aperture heat meter recently described[5] have shown that the Hitex super carbon gives more measured light per unit of heat at the aperture than does the old super carbon. The difference amounts to approximately 15%. As a matter of fact, the Hitex super at 180 amp does not give measurably more total energy at the aperture than does the old super at 170 amp in spite of the 15% advantage in light. It would be expected that this

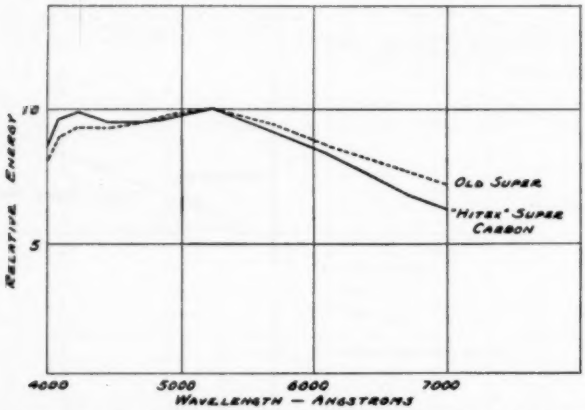

Fig. 4. Spectral energy distribution of light at center of projection screen at maximum light at 170 amp, no film. Curves have been adjusted to approximate same visual intensity of illumination.

magnitude of light increase can, therefore, be obtained with the new carbon without any increase in severity of the heat-on-film problem.

The ½-in. National Heavy Duty Orotip negative carbon is recommended for use with the Hitex super carbon over its entire current range.

The former 13.6-mm super carbons operated best with the axis of the negative carbon intersecting the positive crater face intermediate between the center and the lower lip of the crater in order to obtain an optimum combination of stability, light output and burning rate. The optimum position with the Hitex super occurs with the negative axis shifted a little lower so that it intersects the crater face approximately at the lower lip.

Summarizing, the Hitex super carbon makes it possible to project more light on the projection screen that could previously be done and at the same time this is accomplished with a worth-while reduction in cost of operation resulting from improvements in the efficiency of utilization of carbon and of electric power.

NOTE: The terms Hitex, National and Orotip are registered trade-marks of the National Carbon Div., Union Carbide and Carbon Corp.

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Television Recording Camera Intermittent

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Summary—**This is a brief description of the Wall 16-Mm Camera Intermittent that lends itself easily to meet the demands for fast film pull-down in television recording cameras. Pull-down time has been cut to .005 sec.**

The advent of television broadcasting brought new functional requirements for motion picture cameras. Probably the most outstanding of these problems was the intermittent, for this truly is the heart of the camera.

It seems that in order to synchronize the difference in frame frequencies between television, having 30 frames/sec and the standard motion picture camera with 24 frames/sec, it is necessary to have not more than 72° of shutter or film pull-down time in the motion picture camera. It is also necessary to make allowances for losses in the shutter timing devices due to various electrical and mechanical functional tolerances.

All factors combined, it is therefore necessary in some extreme cases to limit the film pull-down time to 40°, or one-ninth of a cycle.

In analyzing this 40° pull-down time, it will be found that 40° is one-ninth of a picture cycle, which, at the rate of 24 picture cycles/sec, gives the actual time for pulling the film from one frame to the next as a little less than .005 sec.

Although the length or mass of film moved by the intermittent is approximately 10 in. in length and consequently has very little weight, still, in the case of the 16-mm film which has sprocket perforations on only one edge, there is some danger of tearing the film at the sprocket perforations if the film is started too quickly.

This intermittent reduces such possibilities to the minimum because of its slow starting and stopping.

This intermittent lends itself very nicely to changes in film pull-down time, for although the Wall Standard 35-mm intermittent has a film pull-down time of 157°, this can be greatly reduced in either the

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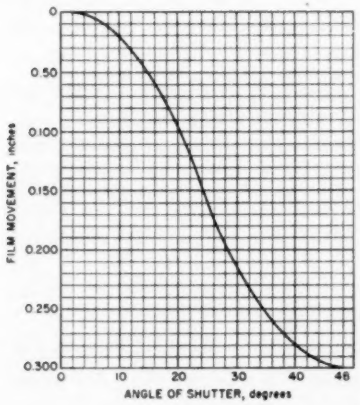
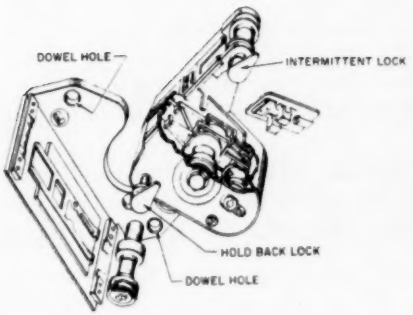
35-mm or the 16-mm intermittents by simply changing the working angle of the cams.

The reduction of the pull-down time was no new problem as patents were already secured covering fast pull-down on the 35-mm intermittent, so it merely became a problem of applying the earlier work to the 16-mm intermittent.



Lineal movement of film in .001 in. per degree of angular rotation of shutter during intermittent pull-down cycle.



Wall 16-Mm Camera Intermittent.

One of the unique features of this intermittent is that the cams have two dwell and two working periods in each cam cycle. Also, the cam follower has two parallel surfaces that are at all times in contact with opposite sides of the cams; thus the cam in reality is both active and complementary in its performance.

In designing the 16-mm intermittent, we therefore decided to use the same construction that has proven so satisfactory in the 35-mm intermittent. Thus, by reducing the working angle of the cams to the minimum angle permissible, we were able to reduce the pull-down angle to 81°58′5″ but this was still 41°58′5″ greater than the minimum of 40°.

In the Wall Intermittent, the pull-down lever has its fulcrum point at one end and the pin that engages and pulls down the film is in the other end and at some point in between is located the cam; therefore, the effective angle of rotation of the cam is the normal working angle plus the angle which the lever forms in pulling down the film.

So, by changing the direction of rotation of the cam, the effective angle of rotating would be the working angle of the cam minus the angle of the pull-down lever. In this manner, we were able to reduce the pull-down angle to 65°54′15″ which was still greater than the minimum of 40°.

By offsetting the center of the intermittent cam shaft with the drive shaft, we were able to gain the necessary angle.

Due to rapid acceleration and deceleration of the pull-down lever, the intermittent was at first quite noisy. We found that the intermittent moved slightly on the gibs holding it in place. This movement was eliminated and the noise greatly reduced by putting into the camera case hardened dowels which fit into hardened bushings in the intermittent frame. Also, by employing an interrupted thread type of fastening device, we have reduced the noise level to the point where on a 60° pull-down intermittent it is almost impossible to hear the intermittent run.

In tests conducted by us in cameras without a shutter and using positive stock in either a 40° or 60° pull-down intermittent, the pictures were steady, without a ghost, and with clearly defined frame lines.

Motion Picture Color Photography of Color Television Images

By W. R. FRASER and G. J. BADGLEY

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Summary—**By combining the techniques and equipment required for motion picture recording of radar PPI (Plan Position Indicator) scopes and television kinescopes, acceptable 24-frames/sec color motion pictures have, for the first time, been obtained from color television kinescopes. This has been accomplished by suitably modifying a professional type 16-mm motion picture camera and adding a specially designed high-speed 25-mm *f*/0.7 lens.**

While it is true that World War II temporarily interrupted the progress of commercial television, it is also true that numerous wartime research and developmental projects contributed in no small measure to the rapid development of television as we know it today.

The growth of television since 1946 has been truly phenomenal, especially in the larger metropolitan areas of New York, Philadelphia, Chicago and Los Angeles. The requirement to record television programs, which includes both the audio and visual record, immediately presented itself. Special cameras[1] and techniques[2,3] were developed for the purpose of furnishing documentary films and films for network syndication.

The military applications of television are numerous. The early "block"[4] and "ring"[5] television equipments were developed during World War II for air-borne reconnaissance. "Stratovision" broadcasts in 1948 and 1949 vividly demonstrated the possibilities of air-borne television to the American public. As in the case of commercial television, a documentary record of the "telecast" sometimes is mandatory and in many instances proves invaluable.

The improvement of modern color films during recent years has been a boon not only to the motion picture industry and the U.S. amateur photographer, but to science as well. Medical photography, to cite one instance, becomes many times more effective and valuable when viewed in color. The study of rocket fuels and their combustion

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characteristics is also facilitated by color photography. It is reasonable to predict that a similar revolution will occur when color television is given the green light by the Federal Communications Commission. The existing requirement to record black-and-white telecasts will, without doubt, be extended to cover a color recording of a color program from the color television screen. A whole new field of problems peculiar to color photography, including color temperature and color balance, in addition to gamma and density, will rise to complicate the job of the color cinephotographer.

MOTION PICTURE RECORDING OF RADAR SCOPES

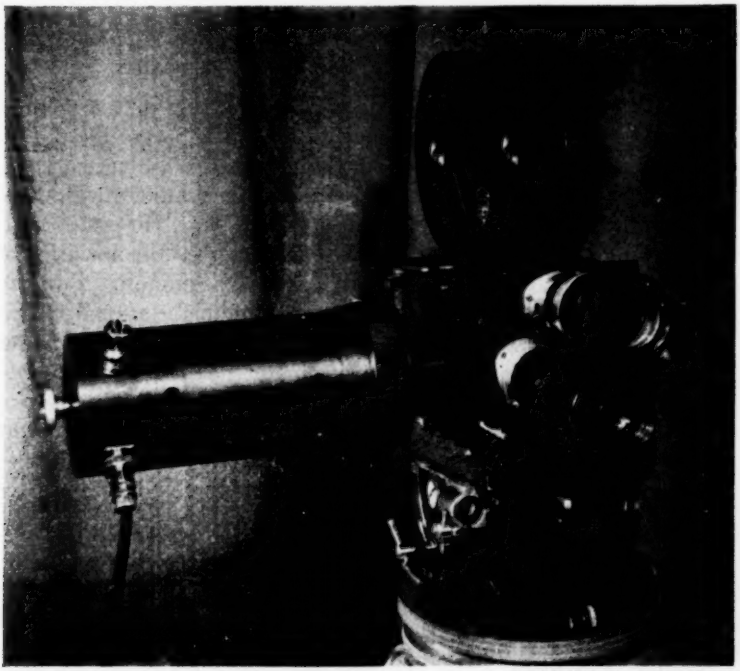
During the War, David Gray of the Polaroid Corp.[6,7] developed a special 25-mm focal length lens with an aperture of $f/0.7$. This lens was mounted on a Cine Special 16-mm motion picture camera and successful motion pictures of the PPI (Plan Position Indicator) type of radar scope images were obtained. This equipment was rotated among several agencies including the Naval Research Laboratory, Naval Photographic Center and the Massachusetts Institute of Technology. However, this arrangement was not too satisfactory, and in 1948 the Naval Photographic Center contracted with the Polaroid Corp. to build a new and improved 25-mm $f/0.7$ lens. In the design of this lens, high speed was the guiding requirement and, consequently, other aberrations including "barrel distortion" were tolerated. In spite of this, a resolution of 20 lines/mm on the axis was achieved which is quite adequate for recording PPI type of radar targets.

High speed lenses, as a general rule, have a shallow depth of field and a short back-focus distance. Before the $f/0.7$ lens could be mounted on a Mitchell 16 motion picture camera, it was first necessary to mill out a $\frac{1}{8}$-in. deep circular section around the camera aperture to permit focusing the lens. Fortunately, in radar recording, the object distances are usually 12 to 18 in., which permits focusing in the "racked out" lens position. A new lens turret to hold the $f/0.7$ lens and three other conventional lenses completed the interim model radar motion picture recording camera (Fig. 1). Successful exposures have been secured of PPI radar scope images or targets at 24 frames/sec with a "G" filter using this modified camera. A new radar recording camera, designed and now being built by G. J. Badgley, will have a shutter opening in excess of 310° which will increase the exposure time by approximately 80%.

BLACK-AND-WHITE TELEVISION RECORDING

The first black-and-white television recordings secured by the U.S. Naval Photographic Center were made on March 21, 1946, at the Naval Air Station, Anacostia, D.C., during the public demonstration of the Navy "block" and "ring" air-borne television equipment.

NOTE: "Block" equipment operates at a frequency of 40 fields/sec non-interlaced, while "ring" equipment operates at 40 fields/sec interlaced.



Official U.S. Navy Photograph

Fig. 1. Specially modified Mitchell 16 motion picture camera with 25-mm $f/0.7$ lens and variable synchronous motor.

Subsequent recordings with conventional lenses were made at 20 frames/sec using a Berndt-Maurer 16-mm camera with a fixed 180° open shutter.

Recording would be greatly facilitated if commercial television

were operated at 96 fields/sec interlaced instead of at 60. Such a frequency would permit recording at 24 frames/sec with a simple 180° open shutter instead of a special camera equipped with a 288° open shutter as is required by the present 60-fields/sec system. However, 15-frames/sec recordings of commercial telecasts have been made with the 180° open shutter Berndt-Maurer Camera.

A number of special recordings including underwater television and "Stratovision" telecasts were also made at 15 frames/sec (synchronous speed). During the past several years, the Naval Photographic Center has been quite active in cinephotography and, in addition, close liaison has been maintained with industry.

COLOR RECORDING OF CBS COLOR TELEVISION

On August 18, 1949, CBS (Columbia Broadcasting System), under the sponsorship of the Smith, Kline and French Laboratories, put on the first experimental color television broadcast in Washington, D.C., for the Federal Communications Commission and other government officials. The program originated at Johns Hopkins Hospital, Baltimore, Md., and was telecast to Washington over the facilities of WMAR-TV, Baltimore, and WMAL-TV, Washington. Two receivers were installed at the District of Columbia National Guard Armory and permission was secured to set up our Berndt-Maurer camera for a few minutes in front of one of the color receivers. A 25-mm $f/1.4$ Cine Ektar Lens and daylight type Kodachrome were used. Exposures were made at 15 frames/sec synchronous, and at approximately 8 and 4 frames/sec using the hand crank. The results were quite promising in that the exposure at both 4 and 8 frames/sec was adequate.

NOTE: A portion of this footage was shown in the Navy Film on High Speed Photography during the October, 1949 Hollywood Convention of the Society of Motion Picture Engineers.

During September, 1949, hearings were convened in Washington, D.C., by the Federal Communications Commission on the subject of color television, and comparative tests of RCA, CBS and Color Television, Inc., color systems were scheduled in Washington, D.C., for October, 1949. Technicians at the Naval Research Laboratory had modified a black-and-white television receiver for CBS color, so the opportunity to try another color recording became available. Our previous exposure data indicated that by using the radar recording

camera equipped with a single-phase synchronous motor, and a 180° open shutter, the possibility of getting adequate exposure at 24 frames/sec was within reach. A series of tests with the $f/0.7$ lens mounted on the Mitchell 16 was necessary in order to reduce the "shutter bar" to a minimum. (When conventional lenses are stopped down, the shutter bar, if present, becomes more sharply defined.) It was finally determined, by cut and try methods, that a shutter opening of approximately 179½° produced a barely visible shutter bar on the film at 15 frames/sec when the conventional lenses were stopped down to $f/11$. When the lenses were wide open, the shutter bar practically disappeared. Actually, no shutter bar was apparent when the shutter opening of 177° was tried with the $f/0.7$ lens on the camera. An in-

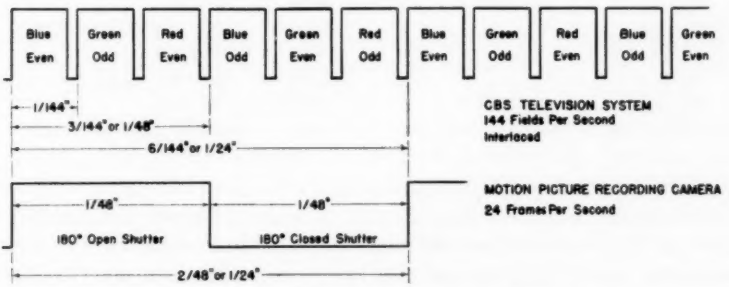


Fig. 2. CBS color television recording system.

duction motor was converted to a synchronous motor and a reduction gear box of 1,800 to 1,440 rpm constructed.

The Naval Research Laboratory receiver, as it turned out, did not have sufficient light output for 24-frames/sec recording with the $f/0.7$ lens. Both Kodak Type A and Ansco Tungsten color films were used. In order to get greater effective emulsion speed, the Ansco film was given twice the normal time of development in the first developer. Adequate facilities were not readily available for special developments, and consequently only 100 ft of film was given this type of processing. This treatment did produce a better film record, but the additional work involved was not worth the effort. The Ansco Company specially developed some Ansco Tungsten color film, but the effective emulsion speed was still not adequate. It was then considered that the work involved by special color processing

could not be justified and it was decided to concentrate on standard color development.

A special Navy Type C 16-mm camera equipped with the $f/1.4$ Cine Ektar Lens, a 4- and 8-frames/sec gear box and synchronous motor were also tried with limited success. This camera is a modified Cine Kodak magazine type equipped with elliptical gears designed to increase the exposure time per frame. Good color recordings were obtained at 8 frames/sec with this camera.

The CBS "Field Sequential" color system lends itself particularly well to color cinematography. The sequence of scanning is as follows:

Color Frame	*Time*	*Scan No.*	*Color*	
1 $\frac{3}{144}$	$\frac{1}{144}$ sec	1	Blue	odd lines
1 or	$\frac{1}{144}$	2	Green	even or interlaced lines
1 $\frac{1}{48}$ sec	$\frac{1}{144}$	3	Red	odd lines
2 $\frac{3}{144}$	$\frac{1}{144}$	4	Blue	even or interlaced lines
2 or	$\frac{1}{144}$	5	Green	odd lines
2 $\frac{1}{48}$ sec	$\frac{1}{144}$	6	Red	even or interlaced lines

A combination of 1 blue, 1 green and 1 red scan in $\frac{3}{144}$ or $\frac{1}{48}$ sec makes up one complete color frame. A motion picture camera operated at 24 frames/sec synchronous will therefore record every other complete color frame when a 180° open shutter is employed (see Fig. 2). Double and other even multiple exposures are possible in accordance with the following table:

Camera speed, frames/sec	24	*Color TV frames recorded per film frame*	1
	12		2
	6		4
	3		8
	1½		16

For the purpose of conducting exposure tests, a variable synchronous motor with the above speed markings would be ideal. Fortunately, the Producers Service Co., Burbank, Calif., recently announced a $\frac{1}{15}$-hp synchronous motor with a built-in variable speed transmission that includes the aforementioned synchronous speeds (Fig. 1).

The American Medical Association Convention held in the Washington, D.C., National Guard Armory, December 5 to 9, 1949, presented a rare opportunity to record color television. Under the sponsorship of the Smith, Kline and French Laboratories, surgical opera-

tions performed at the Johns Hopkins Hospital in Baltimore, Md., were broadcast by microwave relay to the American Medical Association Convention. Arrangements were made to record, and on December 8 (the next to last day) it was discovered that CBS was operating at a picture frequency of 150 fields/sec instead of the usual 144 fields. This "slight" change made our 24-frames/sec color television recording camera useless. Fortunately, by working until after midnight, a new 25-frames/sec gear box was designed and manufactured.

On the morning of December 9, 1949, the first completely successful color recordings were made from the CBS Color Television receiver at the rather unorthodox speed of 25 frames/sec. Portions of two surgical operations were recorded: Resection of Colon, by Harvey B. Stone, M.D.; and Total Hysterectomy, by Richard W. Lelinde, M.D.

The following 16-mm color film, totaling 1300 ft, was exposed: two 400-ft rolls of Type A Kodachrome; one 400-ft roll of Ansco Tungsten and one 100-ft roll of Commercial Kodachrome.

As the color temperature of the CBS television tube was approximately 3800–4000 K (degrees Kelvin), C–¼ and C–⅛ Harrison color filters were used to reduce the color temperature of the television to match more closely the color temperature of the film. The quality of the color prints compared favorably with results usually obtained by direct 16-mm color cinephotography. As usual, however, there was a definite division of opinion concerning the relative merits of Kodachrome and Ansco Tungsten color films.

Subsequent recordings were made at 24 frames/sec from the CBS color monitor in Washington, D.C., during January, 1950. The best results, however, were obtained from the Smith, Kline and French receivers, which appear to have a greater tube light output. Portions of these recordings, in addition to the Corneal Transplant Operation recording, were demonstrated by CBS before the Federal Communications Commission in Washington on March 24, 1950.

The Atlanta Graduate Assembly of the Fulton County Medical Society under the sponsorship of the Smith, Kline and French Laboratories presented a three-day program of color television of surgical operations and clinics on February 6, 7 and 8, 1950, in Atlanta, Ga. This time, however, the program was telecast at 144 color fields/sec which permitted 24-frames/sec color cinephotography. Philip Bang, who was one of the early pioneers of sound recording in the South, made sound recordings of the telecast with a synchronous-driven

Fairchild 16 disc recorder. This occasion marked the first time that a color recording was made of a color telecast with the accompanying sound. Color composite prints were made and among them was the spectacular corneal transplant operation that has received nationwide publicity during the past several months.

COLOR RECORDING OF RCA COLOR TELEVISION

Arrangements were made in October, 1949, to attempt a recording of the RCA "dot sequential" color television system and after several unavoidable delays, the first color recording was made at the RCA Silver Spring Laboratory on March 10, 1950. This initial recording was made at 15 frames/sec with a 180° open shutter, the exposure time being $\frac{1}{30}$ sec. Referring to Fig. 3, it is evident that the same ex-

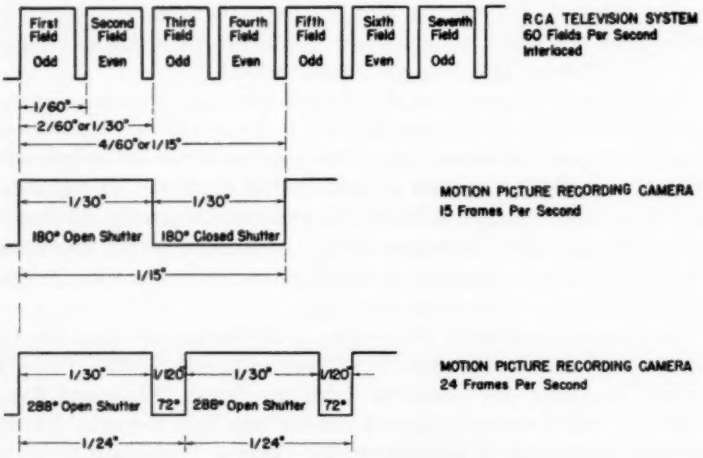


Fig. 3. RCA color television recording system.

posure time of $\frac{1}{30}$ sec is obtained at both 15 frames/sec with a 180° open shutter and at 24 frames/sec with a 288° open shutter. Completion of the new "Badgley" camera equipped with a 288° open shutter and the $f/0.7$ lens will permit recording of RCA color television at 24 frames/sec.

The color temperature of the RCA color television receiver image was approximately 6500 K. During the first recording attempt, the following films and filters were tried: Daylight Kodachrome with

Harrison C–¼; Daylight Kodachrome with no filter; Commercial Kodachrome with Wratten No. 83 and Ansco Tungsten with Ansco No. 11 conversion filter.

All exposures were good and the best result was obtained using commercial Kodachrome and the Wratten No. 83 Filter. Strangely enough, it was the consensus of opinion that the film record was superior in quality to the image on the color television receiver as viewed with the naked eye. This phenomenon may be partially explained by the fact that the recording camera lens was located on the axis of, and normal to, the color television image, whereas the observers were force to view the image from an "off center" position.

The amount of light emitted by the RCA "three tube," dichroic mirror receiver, as with the CBS receivers, permitted good exposures to be secured at a light meter reading of from 0.75 to 1.00 foot-candles measured at the recording camera lens with a Model 603 Weston foot-candle meter.

COLOR RECORDING OF CTI COLOR TELEVISION

On March 16, 1950, the first experimental recording of a CTI (Color Television, Inc., San Francisco, Calif.) "line sequential" color telecast was made from an RCA three-tube receiver equipped with dichroic mirrors. This recording was made at 15 frames/sec using the modified Mitchell 16 with the $f/0.7$ lens. The present CTI receiver employs rear projection, the image being viewed on a translucent screen. The resulting image in this case is not as bright as the image that appears on a direct view tube. Color Television, Inc., however, expects to have a new, higher light output tube available for demonstration in the near future.

CONCLUSION

If standard speed ($f/1.4$) lenses are to be used for color television recordings, an increase in color film speed or in television tube light output, or a combination of both amounting to two stops (400%), is necessary. In other words, doubling the speed of presently available color film and doubling the television tube light output would permit recording of color television with $f/1.4$ lenses. The major problem thus far has been that of obtaining sufficient exposure and it will remain so until faster color films or brighter color television tubes become available. The use of high light output projection-type tubes shows considerable promise. The quality of the image produced by

the $f/0.7$ lens cannot compare with the results produced by conventional high-grade motion picture camera lenses. The problems introduced by color television are remarkably similar to those encountered in the three-color film process. The experience and knowledge gained through the widespread use of color films will, without doubt, prove most helpful in solving the problems introduced by both color television and color cinephotography.

ACKNOWLEDGMENTS

The authors are indebted to the following companies and individuals whose co-operation and assistance has made this paper possible: Columbia Broadcasting Co., P. C. Goldmark, John Martin and John Christianson; Smith, Kline and French Laboratories, G. F. Roll and Lewis Lang; Radio Corporation of America, George H. Brown and John Million, Sr.; A. K. Litz, U.S. Navy.

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Non-Intermittent Motion Picture Projection

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The numbers and the needs of amateur motion picture projectionists make expedient a restatement or recapitulation of the advantages of non-intermittent motion picture projectors. This is thought necessary on account of the want of due appreciation of the useful characteristics of this type of projector, which the literature published on the subject has revealed.

In a paper entitled "The Problem of Motion Picture Projection from Continuously Moving Film,"[1] a summary of the advantages of non-intermittent projectors was published, which is notable for the number and the importance of those omitted.

Another paper which is believed to undervalue the utility of non-intermittent projectors bears the title, "Is the Continuous Projector Commercially Practical?"[2]

The purpose of this letter is to submit, for the notice of those who require a more adequate amount of data for an appraisal, several additional advantages which were previously passed unnoticed.

In non-intermittent projectors an undisputed advantage is that instead of curtailing the exposure, or stationary period of the image, an additional length of time is assigned to it. The depth, or third dimensional effect brought out by non-intermittent projectors, is believed to be due to the advantage of the lap-dissolve.

Of the useful properties inherent in non-intermittent projectors, one of the most curious is the movement exhibited during a slow lap-dissolve of two successive picture images. As only two film frames take part in the movement, the apparent intermediate positions do not exist in the photographic record; but they are, nevertheless, conveniently introduced by the magic of the lap-dissolve. These movements

REPRINTED: From *Journal of the Optical Society of America*, vol. 39, pp. 505–506; June, 1949; by permission of the Editor.

[1] Fordyce Tuttle and C. D. Reid, *Jour. SMPE*, vol. 20, pp. 3–30; January, 1933.

[2] Lester Bowen and Herbert Griffin, *Trans. SMPE*, No. 18, pp. 147–152; May, 1924.

can sometimes be stopped and started again more than once. In close-ups, the turning of the head or body is often particularly well rendered, with a life-like uniform motion no matter how slowly the change be made. The cause of this curious phenomenon is to be found in the irradiation of the retina. Its greatest advantage to amateurs is that it forms the basis for a successful and inexpensive means of exhibiting slow motion, when the rate of projection is reduced to two or three frames a second, and the taking rates have been at twenty-four or over. The unique slowed motions displayed, and the theory upon which they are based, provide a distinct source of interest and amusement to amateurs.

This useful property of the lap-dissolve is also an important factor in the successful employment of lower rates of projection for amateurs. Many amateur shots can be projected successfully by the non-intermittent projector at rates of from twelve to eight frames a second.

A major advantage, involving higher orders of precision in motion picture registration, is that the registration of the non-intermittent projector can be made as independent of the inaccuracies of the film perforations as the sound track.

The effect of vibration on the definition of the motion picture image is well known. In microscopic work it is very objectionable. In the non-intermittent projector this objectionable feature is avoided because the mechanism has the advantage of operating without vibration.

Graininess, vibration, and errors in registration, are all sources of impairment of the motion picture image, and must be counted among the aberrations. These aberrations still exist and remain a problem in the motion picture image; and optical elements appear to be the only possible means that can be employed to reach and correct them.

Finally, it can be said, the most significant advantage is that the non-intermittent projector lets down the bars and opens the way to new and greener pastures. For, almost within reach, are electrical and photo-electrical means of synchronization, a greatly extended range in rates of projection, higher resolving powers, and larger picture areas.

A Simplified Body-Cavity Camera

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Summary—**The need for a special body-cavity camera in clinical photography is described. Problems in cavity photography are discussed, and diagrams show typical lighting methods. There is an explanation of the Intraflex Camera optical system, the continuous through-the-lens finder and the precalculated iris setting.**

This consideration of body-cavity motion picture photography is confined to the problems of photographing the natural and surgical cavities of the human body which can be made visible to the external camera. These cavities are exposed for photography by the same means as those used by the doctor for visual examination. During an operation, cavities resulting from surgery are held open by various types of clips and clamps: the oral cavity is made visible with the laryngoscope or the throat mirror; the vaginal cavity, by a speculum; the anal cavity, by a speculum or a tubular instrument of the procto-sigmoidoscope type; and the bronci and esophagus by the bronciscope and esophaguscope, respectively.

For visual examination, the areas within these cavities are illuminated by light reflected from a head mirror or by grain-of-wheat lamps attached to the distal end of the scope-type instruments. This illumination, while adequate for examination, is insufficient for motion picture photography.

The first problem of cavity photography, therefore, is that of illuminating the field at some depth within a relatively small passage. This must be done without interference with the camera lens cone of vision which is necessarily positioned coaxially with the cavity. This camera position, in line with the cavity, creates a second problem, that of viewing the field. Any line of sight which will by-pass the camera will be oblique with respect to the cavity; therefore, through-the-lens viewing is indicated. Most 16-mm camera through-the-lens viewers do not provide the continuous viewing essential to maintaining the proper field and focus in cavity photography.

Because of the illumination and viewing problems alone, it is apparent that standard equipment and photographic techniques are

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limited to the more open and shallow cavities. This is borne out by the fact that many fine surgical films, currently used in medical education, are made with art work to illustrate the photographically inaccessible areas.

Many ingenious methods have been devised and used for body-cavity photography. Three of the more common types are schematically illustrated in conjunction with the problem of photographing a field at the distal end of a rectal proctoscope which is a straight tubular examining instrument about 8 in. long and ¾ in. in diameter.

Figure 1 illustrates a system wherein the light source is positioned as close as possible to the camera lens axis. The effectiveness of this arrangement is limited to the amount of light which can be reflected

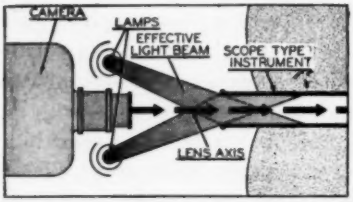


Fig. 1. Use of lamps close to lens.

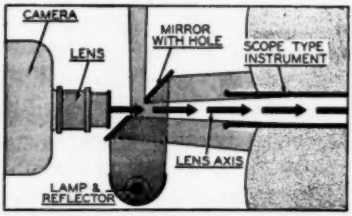


Fig. 2. Use of reflector with hole for lens.

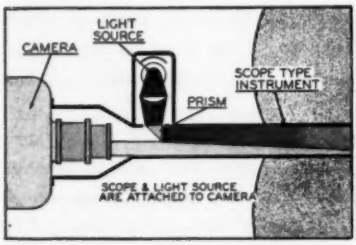


Fig. 3. Prism in camera cone of vision; scope and light source are attached to camera.

through the inside of the tube, as parallax between the light axis and camera axis prevents direct light from reaching the field.

In the arrangement shown in Fig. 2, a mirror with a centrally located hole is positioned coaxially with, and at an angle to, the camera optical axis. Light from an adjacent source is reflected into the cavity by the opaque area of the mirror, and the field is photographed through the hole. In effect, this system is similar to placing lamps close to the lens but offers the advantage of more space for the light

source. A spherical mirror is often used to increase the light concentration at the plane of the field.

Figure 3 outlines a method which is primarily used for directing light into a scope-type of instrument normally attached to the camera

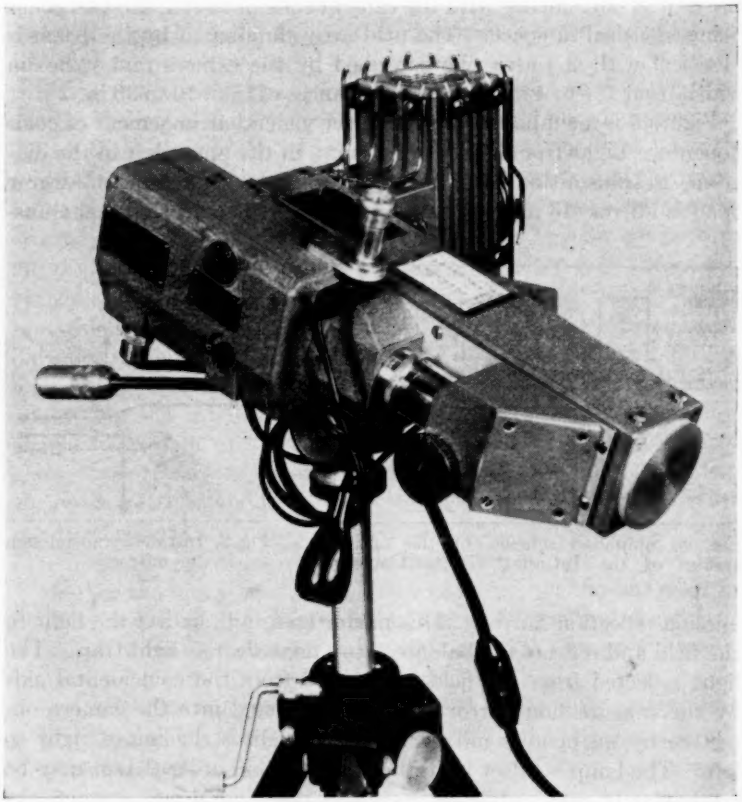


Fig. 4. Model C-3 Intraflex Cavity Camera.

and light source. A mirror or prism, positioned about halfway into the effective camera cone of vision, reflects light from an outside source into the tube. The inside of this tube is highly polished to reflect a maximum of light to the field at the distal end. That half of the camera lens not covered by the prism remains effective. A variation

of this method employs a mirror with a hole to direct light into the scope, and the prism diverts reflected light into a viewfinder.

The Intraflex Cavity Camera is a combination of a 16-mm magazine-loading electric camera and a projection-type light source and optical system (Fig. 4). A beam of collimated light is projected from the unit in coincidence with the camera cone of vision, the two cones being identical in space. The field area illuminated by the beam is identical with the area photographed by the camera and varies in width from 1½ to 4 in. at camera distances of from 10 to 30 in.

Figure 5 is a simplified scheme of the general arrangement of components. Light from a 1000-watt lamp, in the upper left of the diagram, is transmitted progressively through a condenser, 45-degree opaque mirror, 16-mm aperture, projection lens and a special trans-

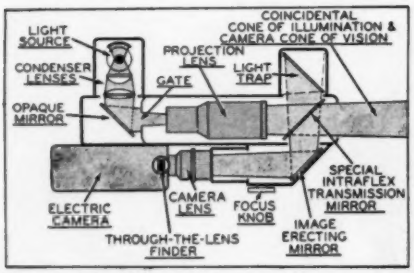


Fig. 5. Simplified scheme of the optical system of the Intraflex Cavity Camera.

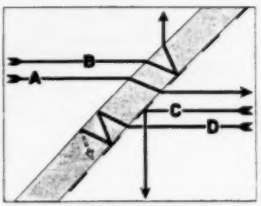


Fig. 6. Intraflex transmission mirror.

mission-reflection mirror. This mirror transmits half of the light to the field and reflects the balance into a nonreflective light trap. The light reflected from the field is diverted from the coincidental axis by the transmission mirror and again reflected into the camera objective by an opaque mirror which normalizes the image right to left. The lamp is offset from the major axis in order that it may be mechanically retained in a base-down burning position when the camera is tilted.

Another special transmission-reflection mirror is positioned in the optical axis between the camera objective lens and the film gate to reflect about one-third of the image-forming light to the ground glass of a magnifying viewfinder. The image formed on this ground glass is in simultaneous focus with the image at the film plane and includes the identical area. This finder remains effective whether the camera

is running or idle and provides a continuous through-the-lens view of the field.

The special transmission mirror used to coincide the cones of illumination and vision is composed of vertical aluminized front surface opaque stripes alternated with clear glass and spaced in such a manner as to prevent the second-surface reflections of the mirror glass from reaching the film. The viewfinder mirror is similar but with a much smaller pattern.

Figure 6 is a schematic cross-section of the transmission-reflection mirror, the heavy lines representing opaque aluminized coating, the lighter lines, clear glass. Line A is a typical ray of light from the projection lens which passes through a transparent area of the mirror to illuminate the field and B is a similar ray which is reflected from an opaque stripe into the nonreflective light trap. C is an image-forming ray, returning from the field, which is reflected into the camera optical system by an opaque stripe. D is a potential image-forming ray which passes through the glass between opaque stripes and is partially reflected by the second surface. This type of ray can cause a ghost image on the film, slightly offset from the major image and of about 4% the intensity. Because of the spacing of the opaque stripes in relation to the thickness and refractive index of the mirror glass, these secondary image-forming rays fall on the reverse side of the opaque stripes and are re-reflected to the second surface. Subsequent reflections are of an order well below the threshold level of the film at the normal exposures and do not record.

Neither the image of the projection aperture nor the image of the field is formed at the plane of this mirror; therefore, there is no stripping of the illumination on the field or on the image at the film plane.

Figure 7 illustrates the Intraflex applied to the proctoscope problem. The camera is positioned coaxially with the scope and light is projected directly onto the field.

Figure 8 is an arrangement for photographing the larynx, posterior nose or any field to which a straight light path does not exist. A mirror is used to direct light to the field, and the camera photographs the reflected image.

The Intraflex is focused by sharpening the image seen on the ground glass screen of the viewfinder. To permit rapid focusing over the relatively large displacement range of the 3-in. lens, a rack and pinion are provided. Rapid focus change is often advantageous when main-

taining sharp focus on instruments moving to and from the camera. The projection lens used in the illumination system automatically focuses the 16-mm light aperture on the same plane as the camera objective by mechanical linkage. This insures even illumination and absence of filament image on the field.

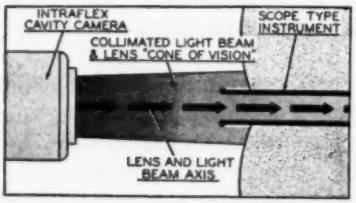


Fig. 7. Using the Intraflex Cavity Camera to photograph a field exposed with a scope-type examining instrument.

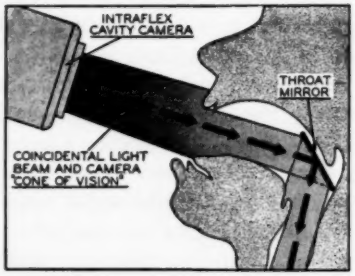


Fig. 8. Photographing the throat.

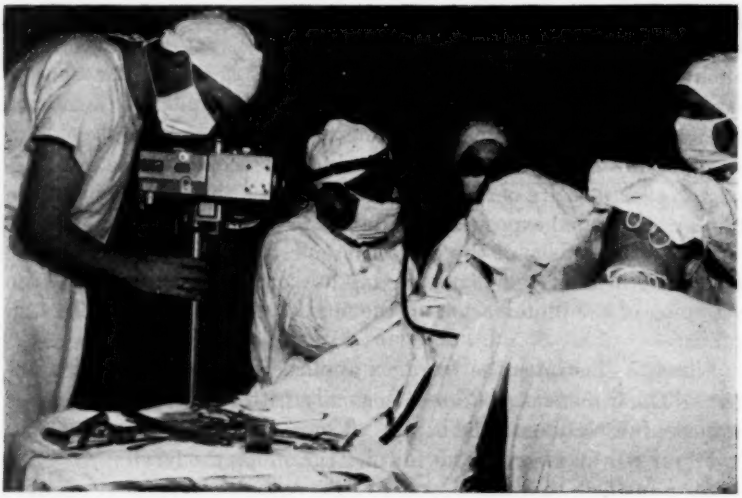


Fig. 9. Model B-3 Intraflex photographing an antro-ethmosphenoidal operation.

Illumination of the field varies only with the distance from the camera. The focusing dial is engraved in alphabetically designated increments which are tabulated on exposure charts for each combination of film and camera speed. After focusing, reference to the indi-

cated letter on the proper chart will designate the correct iris setting. Accurate color values are especially important in medical film.

This camera may be mounted on most types of tripods or cranes. The importance of accurate alignment of camera and cavity indicates the use of a readily and universally adjustable support.

The Intraflex Camera is an effort to solve the cavity photographic problem and to eliminate such technicalities as exposure calculations, distance estimating, camera threading and winding and to make highly predictable results possible for the non-photographically experienced doctor, nurse, or medical assistant.

Even with equipment which simplifies the photographic problem, the cavity photographer will have his troubles, especially in surgical work. The success of the operation or treatment is the primary consideration; the cameraman and his equipment are incidental. Traffic between the camera and the cavity is very heavy in instruments, hands and heads. Shots are made when and if the opportunity prevails. Nine camera starts out of ten are prematurely terminated because of interference. A full-length sequence is the exception. One inch of movement of the patient across the small field will cause the resulting projected image to fly halfway across the projection screen. All in all, the photographer will emerge from the ordeal feeling that he has worked harder than any member of the operating crew.

NOTE: The color motion picture which illustrated this paper contained sample footage of most of the body cavities together with a complete filming of the "Transantral Surgical Route to the Sphenoid Sinuses." According to the surgeon who originated this now widely used technique some twenty years ago, this was the first successful motion picture of the operation. The entire procedure was filmed through an opening ¾ in. in diameter in the anterior wall of the antrum, under the upper lip, and progressed into the head to a point at the intersection of a line between the temples and one extending backward from the bridge of the nose, an area very close to the exact center of the head (Fig. 9).

16-Mm and 8-Mm Motion Pictures Committee Report

By H. J. HOOD, Chairman of the Committee

It is some time since your 16-Mm and 8-Mm Motion Pictures Committee has made a formal report; however, that is no indication of inactivity. For at least the past couple of years, most of the Committee effort has gone into the development of engineering standards. One of the first projects brought to a successful conclusion by the present Committee was a group of four American Standards establishing dimensions for picture apertures in cameras and projectors, published in the April, 1950, Journal. Now nearing the end of the long, and sometimes rocky, trail leading to approval as an American Standard are proposals relating to a uniform zero point for focusing scales on 16-mm and 8-mm cameras, mounting threads and flange focal distances for camera lenses, A and B windings for 16-mm film raw stock with perforations along one edge, 16-mm motion picture projection reels, splices for 16-mm films for projection and edge numbering of 16-mm film.

Many of you will remember an outstanding paper on sprocket design published in the June, 1947, Journal. When this Committee studied the possibility of incorporating the technical material in that paper in a Standard, the conclusion was reached that it was not suitable for standardization even though it would be useful to the very men who are likely to keep a book of Standards at hand. This dilemma led directly to approval, by the Society, of the scheme of printing the sprocket design data, and possibly other suitable technical matter, in the Standards' format but labeled "Recommendations" to indicate that it is engineering information rather than a formal standard.

A large subcommittee, under the leadership of E. W. D'Arcy, is working diligently on standards for 16-mm sound reproducer characteristics. That undertaking has turned out to be virtually a research project. Several group "listening tests" and discussions have been carried out. Wide circulation of tentative recommendations can be expected soon. One purpose of this proposed recommendation is to

Presented: April 27, 1950, at the SMPTE Convention in Chicago.

establish, for the equipment used in reviewing 16-mm sound films, a quality level which will eliminate from the appraisal what we might call the "allowance for equipment" factor.

Our Committee is getting well started on drafting standards for projection lamp bases. This is a most timely project as an improved design is necessary, particularly for the new professional and semi-professional projectors. On April 26 representatives of the lamp and projector manufacturers met and agreed on the basic outlines for the new lamp. Unless there is some unexpected difficulty, this standardization should be accomplished fairly quickly.

As the projects listed above are brought to a conclusion and removed from our agenda, others will take their place. For example, a start has been made on standards for camera spools, 8-mm projection reels, 8-mm splices and 16-mm laboratory-type splices.

Also regarding standards, we should note the increasing amount of explanatory material incorporated in several of the standards mentioned above. This is believed to be a desirable trend.

Outside of the field of standards, our Committee has had one major undertaking on its books for quite a while: the writing of a new edition of the booklet on projection practice published in 1941 as a Journal reprint. Our lack of accomplishment in this direction may be attributed to the concentration most of us have had to apply to catching up after the war. We won't be able to use that alibi much longer.

At the last meeting of this Committee, in New York on January 31, there was preliminary discussion which may lead to three new test films.

This Committee has a wide field in which to range. While we have made a conscious attempt to maintain a diversified membership, there is always a chance that we will overlook some project we should consider. In short, we invite your suggestions and comments.

Screen Brightness Committee Report

By W. W. LOZIER, Committee Chairman

THE LAST REPORT of this Committee was presented at the October, 1947, meeting of the Society and published in the March, 1948, JOURNAL. That report told of the survey by the Screen Brightness Committee on 18 theaters of various sizes and locations. That survey brought forth interesting and important indications of theater practice and the need for more extensive study; however, a further survey was postponed until more suitable instruments were available, it having been decided that visual type meters requiring a subjective photometric balance are inherently unsuited to this task.

Specifications and Methods

The Committee has undertaken the task of writing performance specifications on meters for photometric measurements of motion picture screens and also formulation of methods of measurement using these meters.

It is realized that the screen brightness problem involves three elements.

(1) Incident illumination, generally measured in foot-candles.

(2) Screen reflection factor, generally expressed as ratio to a perfectly diffusing and reflecting screen.

(3) Reflected screen brightness, generally measured in foot-Lamberts.

These three quantities are connected by the following relation:

Screen Brightness = Screen Reflection Factor × Screen Illumination.

The measurement of any two of the above three quantities will permit calculation of the third. The measurement of incident illumination on theater screens is a relatively simple procedure for which satisfactory meters are available. It is the measurement of one or the other of the remaining two quantities, that is, screen reflection factor or reflected screen brightness, which presents the major problem.

PRESENTED: April 27, 1950, at the SMPTE Convention in Chicago.

Measurement of Screen Brightness and Screen Illumination

The Committee has worked with instrument manufacturers with the goal of obtaining combination meters suitable for measurement of incident screen illumination and reflected screen brightness. Progress has been carried to the point where it has been shown that portable meters of desired sensitivity can be built. However, because of the requirements for a rather sensitive meter element for measuring the photoelectric current, it appears doubtful whether the cost can be reduced to that for a simple foot-candle meter or to a level low enough to bring about widespread distribution and usage.

Screen Reflectivity Meters

Further efforts are being made along the lines of some method which will measure incident illumination by means of an inexpensive meter and will also determine screen reflection factor. Measurement of these two quantities would permit calculation of the screen brightness as simply their product. It may be possible to develop a simple apparatus for determining the screen reflection factor which will employ the same meter as that used for measurement of incident screen illumination.

Extension of Theater Screen Brightness Survey

The Committee has been asked to extend the screen brightness survey to approximately 100 theaters to obtain a cross section of theater screen lighting practice. Plans for conduction of this survey are now being made.

Preferred Screen Brightness Levels

The Committee is looking into the problem of preferred screen brightness levels in indoor and outdoor theaters. As a preliminary step, a survey is being made of the pertinent scientific work already done on this problem. If the necessary scientific information is not available, consideration will be given to formulation of tests and experiments which will provide information basic to rational determination of preferred screen brightness levels under various conditions.

Engineering Committees

The semiannual conventions of the Society offer an opportunity for the engineering committees to meet and carry on their work with considerably greater ease than at other times of the year. During the week of the 67th Convention in Chicago, nine engineering committee meetings were held with nearly 100 members in attendance. A few of the highlights of these meetings follow:

16-Mm Projection Lamps

An outstanding example of the industry's co-operation to achieve standards in the best interests of the consuming public has been the work on projection lamps by the 16- and 8-mm Committee. Under the leadership of Henry Hood, the manufacturers of incandescent projection lamps and the 16- and 8-mm projector manufacturers got together to discuss the possibility of establishing one standard for the recently introduced medium-focus, base-up lamps.

Prior to this meeting, two manufacturers, namely General Electric and Bell & Howell, had proposed designs for the mounting dimensions for this type of lamp. Both companies, however, in the interests of establishing one standard, agreed to dedicate their patent rights to the public if the Committee decided to accept their design as the standard. As it turned out, the G.E. proposal was accepted and outline drawings giving the pertinent dimensions have been distributed to the Committee for ballot action.

16-Mm Sound Reproduction

Ever since the war, manufacturers have been trying to improve the quality of 16-mm projectors. Recently, three new models of high professional quality have been introduced. If these new projectors are ever to receive wide acceptance, the general commercial quality of 16-mm release prints will have to be improved. To meet this end, the Committee under E. W. D'Arcy has been at work for almost two years trying to establish standard review room conditions for judging the quality of such prints.

At the meeting in Chicago, it was agreed to revise an earlier draft of these recommendations so as to specify not only the frequency response characteristics of such a system but also the acoustical qualities of the various review rooms and other pertinent requirements for the reproducer itself. A revised draft incorporating these changes is now in the hands of approximately 80 people who are qualified to judge its acceptability. If no adverse criticisms are received within the next 30 days, it will be published in the JOURNAL and publicized as widely as possible in the hopes that 16-mm producers and processing laboratories will adopt these recommendations as a quality control measure.

Film Dimensions

Over the past 30 years there have been many discussions within the motion picture industry concerning the desirability of establishing a single perforation for both positive and negative 35-mm film. Since 1916 there have always existed at least two types of 35-mm perforation. Recently, however, with the increased interest in color, the whole question has again been under review by the Film Dimensions Committee under Dr. E. K. Carver's chairmanship. In April, 1949, the Committee recommended the adoption of the so-called Dubray-Howell per-

foration, as the single standard, and it was described in the JOURNAL of that month.

Shortly after publication, however, Ansco pointed out that while this proposal was probably superior to present practice, there might be a perforation which was even better and Ansco proposed another design. At the Chicago Convention, Ansco representatives presented extensive test data, indicating that their proposal may be superior and certainly throwing doubt on the advisability of tying off on any new standard too quickly.

Consequently, further tests will be run by Ansco as well as by the Motion Picture Research Council in an attempt to determine the most desirable design. It was strongly urged by all concerned, however, that these tests be conducted as rapidly as possible since there may never be another opportunity to replace the two present standards with a single standard satisfactory for both negative and positive films. W. V. Wolfe, President of the Research Council, warned that even a delay of six months may be too long since many of the new color processes are already adopting standards.

Society Announcements

Dues payments from outside the United States must be made in U.S. dollars. The dues payments of all new members after July 1 are required to be in U.S. dollars; and, of course, all payments of annual dues are subsequently to be made in U.S. currency.

June brings graduates—we are reminded by our Student Chapters at New York University and at the University of Southern California, and also by some interesting information from the Rochester Institute of Technology.

For information about Society student members being graduated, or about students seeking summer work, the industry is advised to write:

New York University: Faculty Adviser, Dr. Robert Gessner, Washington Square College of Arts and Sciences, New York University, Washington Square, New York 3.

University of Southern California: Faculty Adviser, Mr. Wilbur T. Blume, Acting Head, Department of Cinema, University of Southern California, 659 W. 35 St., Los Angeles 7, Calif.

Rochester Institute of Technology: C. B. Neblette, Supervisor, Department of Photographic Technology, Rochester Institute of Technology, Rochester 8, N.Y.

The courses at New York University are given to provide basic cultural training in the liberal arts and sciences and an introduction to, and orientation in, the interpretive problems of motion picture writing and production.

The University of Southern California provides fundamental orientation in the principles of photography and in the tools and techniques of the motion picture profession. There are courses on the philosophical aspects and aesthetics of the film and there is advanced training in production techniques including camera equipment, sound recording, production supervision and the responsibilities of the director, as well as a practical workshop giving guidance in the actual preparation of educational films.

Graduates in photographic technology are coming from the Rochester Institute of Technology. Mr. Neblette of the Institute's Department of Photographic Technology advises that among 94 men and 3 women being graduated in June there are 20 hoping to locate in positions as color technicians doing dye transfer printing, color processing, etc., and 11 in the visual aids field. This Institute class includes for the first time students from the courses in Preparation of Visual Aids, Illustrative Color Photography and Processes of Color Photography. Other students have favored other fields with courses in Portrait, Commercial and Industrial Photography, Offset Lithography and Photographic Technology.

The wrong Journal reached a number of members, mostly along the West Coast. They were somewhat surprised when they received the *Journal of Accountancy* in the wrapper of the April issue of the JOURNAL of our Society. This error on the part of the printer is regretted and we wish to offer immediate replacement of any *Journals of Accountancy* which were received but have not as yet been reported.

Papers Committee

The members of the Papers Committee are now training their sights on the program for the 68th Convention at the Lake Placid Club in October. In the light of program crowding at the last three or four conventions, the Committee has made certain changes in the technical session format and in the Papers Program schedule. Because nearly all papers offered for presentation at several recent conventions were accepted, the Papers Program was filled to the limit with nearly every available moment taken up with their delivery, leaving little if any time for the audience to discuss with the author details of the subject. This has been unfortunate because it is at cross purposes with one of the major reasons for holding conventions. Members should be given an opportunity to express themselves or report on work that they or their companies have been doing, and then should be given a chance to discuss the relative merits of their ideas or proposals, making the discussion time of paramount importance.

The quantity and scope of papers offered for presentation parallels the growth and diversification easily apparent in the Society's engineering committee work, and in the editorial content of the JOURNAL. Assuming that these highly desirable trends will continue, the problem of program crowding will certainly not solve itself, and therefore the Papers Committee has decided to use a somewhat different philosophy in accepting papers for the 68th Convention. All offerings will be considered and the most outstanding will be scheduled for actual presentation at the convention. All manuscripts whether or not presented at the Convention, will be submitted to the Board of Editors through conventional channels. A number of them will no doubt be recommended for presentation at Section meetings or in the event that a group of high-caliber papers on related subjects is available, they may be offered at one or more regional conferences during the year.

The actual Papers Program for the 68th Convention will be limited to three, four or five papers per session, with sufficient discussion time scheduled in advance to make convention week a worth-while investment for engineers who are seriously concerned with the subjects on the program. It is expected that points not covered initially by the author but which arise during subsequent discussion or correspondence will either be incorporated within the final JOURNAL version of the paper or will be added to it as formal discussion of the question and answer type.

Section Meetings

Atlantic Coast

Society members who live in or near New York and were unable to attend the 67th Convention turned out in force on May 24 for the regular monthly Atlantic Coast Section Meeting. They heard a repeat performance of Richard S. O'Brien's paper "Engineering Aspects of Television Studio Staging and Lighting Practices," presented previously at the Convention in Chicago. The Section meeting was held at the Reeves Sound Studios, where Mr. O'Brien of the General Engineering Dept., Columbia Broadcasting System, described a number of rules formulated by the major television production groups at CBS to provide a well-integrated basic program production plan. This systematic organization of staging, lighting, camera operation and direction is assurance in advance that the resulting pictures will be as technically correct and as pleasing as the combined limitations of the television system will allow.

The next meeting of the Section is scheduled for June 28th, with a paper by Robert Cavanagh, Research Engineer for Allen B. DuMont Laboratories: "Telecasting of 16-Mm Film, Using the New Holmes Fast Pull-Down Projector on an Image Orthicon Camera." Television broadcasters and engineers interested in 16-mm equipment and film problems will do well to keep posted on this further step in the direction of television-film evolution.

Pacific Coast Section — USC Student Chapter

Making a break from the conventional, members in the Pacific Coast Section joined with the Student Chapter at the University of Southern California on Tuesday evening, May 16, in presenting the annual dinner meeting of the Section. Held at the USC Department of Cinema, the two groups and a substantial contingent of the Audio Engineering Society enjoyed a buffet dinner, three papers by students and Faculty of the University, and a tour of the Department of Cinema.

Following the dinner, the program opened with remarks by C. R. Daily, Section Chairman, and a showing of the film *Troy A.D. 1950.* The three papers were: "The USC Department of Cinema" by Bernard Kantor; "Construction of a 16-Mm Bolex Camera, Incorporating Design Features Found in 35-Mm Studio Cameras" by John Raymond; and a description by Dan Chapman of the production techniques involved in producing *The Thinnest Slice*, a film made for the School of Medicine showing the development of a technique for slicing organic tissue for observation and photography under the electron microscope. A showing of the film concluded this part of the program.

The Pacific Section has its June meeting arranged well ahead of time. A paper prepared by J. G. Frayne, E. W. Templin and G. R. Crane, "A Professional Magnetic Recording System For Use with 35-, 17½- and 16-Mm Films," will be presented in the Institute of Aeronautical Science Auditorium at 8:00 P.M., Tuesday, June 13. This is another meeting with the Audio-Engineering Society members in the Hollywood area on a topic of interest to both groups. It will be the first description of a new Westrex Magnetic Recording Channel designed particularly for motion picture television and allied fields of sound recording. The complete system will be described in detail and demonstrations of recordings will be given.

Current Literature

THE EDITORS present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic or microfilm copies of articles in magazines that are available may be obtained from The Library of Congress, Washington, D. C., or from the New York Public Library, New York, N.Y., at prevailing rates.

American Cinematographer

vol. 31, no. 3, Mar. 1950

Matts, Miniatures and Meticulous Cinematography (p. 82) F. FOSTER
Magnetic Recording Boon to Budget Film Production (p. 84) D. HARROLD
The Men Who Light the Sets (p. 85) G. TAYLOR
Something New in Color Temperature Calculators (p. 88) R. LAWTON
New Eastman Color Film Tested by Hollywood Studios and Film Labs. (p. 95)

vol. 31, no. 4, Apr. 1950

Filmed Inserts and Special Effects Aid Live TV Shows (p. 124) H. A. LIGHTMAN
Mitchell Announces New Professional 16mm Projector (p. 134)
Bell & Howell's New Professional 16-mm Camera (p. 134)

Audio Engineering

vol. 34, no. 3, Mar. 1950

Magnetic Recording in Motion Pictures (p. 9) M. RETTINGER

vol. 34, no. 4, Apr. 1950

Magnetic Recording in Motion Pictures (p. 18) M. RETTINGER

British Kinematography

vol. 16, no. 2, Feb. 1950

The Heating of Film and Slides in Projectors (p. 38) H. McG. Ross
The Application of Magnetic Recording to Sub-Standard Film Projectors (p. 55) K. G. GOULD and R. I. T. FALKNER

vol. 16, no. 3, Mar. 1950

Acoustics and the Film
I. Optimum Period of Reverberation (p. 73) C. W. GLOVER
II. Acoustic Design of Studios (p. 77) J. McLAREN
Progress Report on Colour Kinematography (p. 83) J. H. COOTE
Trends in Studio Lighting Equipment
I. Light Control Gear (p. 91) L. HEWINS
II. Carbon Arcs (p. 91) C. G. HEYS HALLETT
III. Mercury Cadmium Compact Source Equipment (p. 93) H. K. BOURNE

International Projectionist

vol. 25, no. 3, Mar. 1950

The Geneva Intermittent Movement (p. 7) A. C. SCHROEDER
The 35-mm Projection Positive Film, Pt. V (p. 15) R. A. MITCHELL

vol. 25, no. 4, Apr. 1950

The 35-mm Projection Positive Film, Pt. VI (p. 7) R. A. MITCHELL
Renewed Interest in the Maskless Screen (p. 11)
The Geneva Intermittent Movement (p. 14) A. C. SCHROEDER
Heating of Film by High-Intensity Arcs (p. 17) H. McG. ROSS

Photographic Journal

vol. 90A, Special Number, Apr. 1950

Progress in Kinematography (p. 126) R. H. CRICKS

RCA Review

vol. 11, no. 1, Mar. 1950

Characteristics of High-Efficiency Deflection and High-Voltage Supply Systems for Kinescopes (p. 5) O. H. SCHADE
Adjustments for Obtaining Optimum Performance in Magnetic Recording (p. 38) A. W. FRIEND

Tele-Tech

vol. 9, no. 5, May 1950

RCA Color Kinescope Demonstrated (p. 20)
Magnetic Sound on 8mm Film (p. 25) M. CAMRAS

Tele-Vision Engineering

vol. 1, no. 4, Apr. 1950

Television Optics (p. 4) F. G. BACK

New Members

A new effort in the services of the Society is this listing of new members. Below are those added to the rolls during April, since the 1950 MEMBERSHIP DIRECTORY went to press. Also listed below are those members whose grade has been changed during this period.

It is hoped that this list each month will serve to introduce new members not only to the Society generally but also to their Section Officers and especially to those with common geographical and industrial locations.

The designations of grades are the same as those in the DIRECTORY:

Honorary (**H**) Fellow (**F**) Active (**M**) Associate (**A**) Student (**S**)

ASAKURA, AKIRA, 258 E. First St., Los Angeles 12, Calif. (**S**)

BERLANGA, JULIO A., Artes No. 13-A, Mexico, D.F., Mexico. (**A**)

CANNAN, WILLIAM A., 262 North Drive, Rochester 12, N.Y. (**A**)

CONDIT, WARREN L., 37 Lakeview Ter., Staten Island 5, N.Y (**A**)

CORRADI, AMERIGO, Via Albalonga 38, Rome, Italy. (**A**)

COWETT, PHILIP M., 1521 Tyler Ave., Falls Church, Va. (**A**)

DEBISH, JEROME E., 5353 W. Cullom Ave., Chicago, Ill. (**A**)

DePAUW, HARVEY K., 2298 W. 20 St., Los Angeles, Calif. (**S**)

ELLEN, ROBERT I., 5555 Hollywood Blvd., Hollywood, Calif. (**S**)

EWING, JOHN S., 12690 Elmwood Ave., Cleveland, Ohio. (**A**)

FAYMAN, LYNN C., 5655 La Jolla Blvd., La Jolla, Calif. (**A**)

GREENWOOD, JAMES H., 166 N. Sprague Ave., Pittsburgh 2, Pa. (**A**)

HAINES, WILLIAM H., Electric Specialty Co., Stamford, Conn. (**A**)

HAUGE, CARL W., 9933 Provo Ave., Tujunga, Calif. (**A**)

HENIGSON, ROBERT, 342 N. Highland Ave., Los Angeles 36, Calif. (**A**)

JARMAR, SVEN, Filmstaden, Solna, Sweden. (**A**)

KAGE, EARL W., 217 Elm Tree Rd., Rochester 12, N.Y. (**A**)

KOLBER, JOSEPH, 168 W. Kirkwood Ave., Merrick, L.I., N.Y. (**M**)

KRAMER, AMBROSE W., P.O. Box 588, Alexandria, Va. (**M**)

KRUSE, WILLIAM P., 5751 W. Newport, Chicago 34, Ill. (**A**)

LATIERE, LUCIEN, 151-08—33 Rd., Flushing, N.Y. (**M**)

LEVANTINIER, SHARLE, 1725 N. Normandie Ave., Hollywood 27, Calif. (**S**)

MARSHALL, CHARLES T., 4427 N. Winchester, Chicago, Ill. (**A**)

MILLER, ROBERT W., DeVry Corp., 52 Vanderbilt Ave., New York, N.Y. (**A**)

MORE, EDUARDO, Calle 27, No. 908, Vedado, Havana, Cuba. (**M**)

MORRIS, C. W., Western Theatrical Equipment Co., 337 Golden Gate Ave., San Francisco, Calif. (**A**)

NIEMANN, H. P., 12690 Elmwood Ave., Cleveland 11, Ohio. (**M**)

O'CONNELL, LEON J., 2265 Sedgwick Ave., New York 53, N.Y. (**A**)

PERRY, RICHARD A., 1723 Harvard Ave., Independence, Mo. (**A**)

PETERS, PAUL, 317 West Cowan Dr., Houston 7, Tex. (**A**)

REICH, ROBERT L., 5 Legion Pl., Malverne, L.I., N.Y. (**M**)

RODELIUS, NELSON W., 2749 Reese Ave., Evanston, Ill. (**A**)

ROSE, JAMES M., 240 E. 22 St., New York, N.Y. (**A**)

SWEENEY, DONALD E., 1027 W. 94 St., Los Angeles 44, Calif. (**S**)

TREVOR, DON-MARC, 825 W. 180 St., New York 33, N.Y. (**A**)

YOUNG, IRWIN W., 100 Andover Rd., Rockville Centre, N.Y. (**A**)

WALKER, JOHN J., 414 Arbor Ave., Highland Park, Ill. (**A**)

WRAY, WILLIAM C., 5018 S. Kedvale, Chicago, Ill. (**A**)

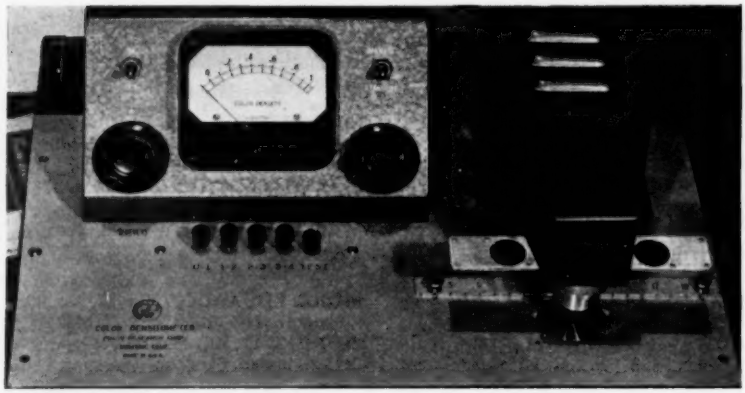
CHANGES IN GRADE

BLUME, WILBUR T., 15223 Ermanita St., Gardena, Calif. (**S**) **to** (**M**)

WYBROW, ERIC, 10435 Dunlear Dr., Los Angeles 64, Calif. (**A**) **to** (**M**)

New Products

Further information concerning the material described below can be obtained by writing direct to the manufacturers. As in the case of technical papers, publication of these news items does not constitute endorsement of the manufacturer's statements nor of his products.

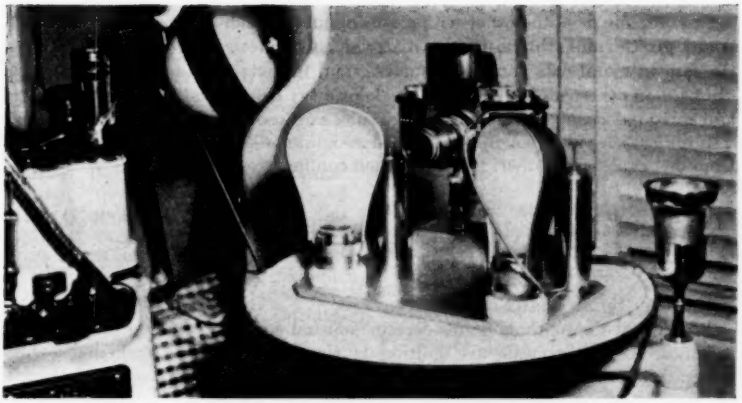


The Color Densitometer above has been developed by Photo Research Corp., 127–129 W. Alameda Ave., Burbank, Calif. It is for measuring over-all color density as well as the effective density of each of the color layers in color film.

The density of the individual exposures of the sensitometric strip are read on the densitometer and are plotted against the individual steps which produced them. When these plotted points are connected by a smooth curve, there is obtained the H & D characteristic curve of that particular film or emulsion. Such curves are used as a guide in the determination of proper lamp current, developing solution and processing time and temperature.

In the case of subsequent laboratory operations — duping, the making of separation negatives, printing and optical work — the number of possible applications becomes much greater. If the color original is not in perfect balance, corrective measures will be applied at this stage, and in order to apply these intelligently it is necessary to know the density range in the three bands employed, blue, green and red, as well as to know the diffuse density reading of masks. If the original is in balance, such information is necessary to insure retention of this condition in future copies. For such purposes an ordinary densitometer is of little assistance, and it is for these that the PRC Color Densitometer has been created.

SMPTE Officers and Committees: The roster of Society Officers was published in the May JOURNAL. The Committee Chairmen and Members were shown in the April JOURNAL, pp. 515–22; changes in this listing will be shown in the September JOURNAL.



The Gibbs Photodont is here shown on a dental bracket table with a Kine Exakta V Camera, for which the exclusive U.S. distributor is Exakta Camera Co., 46 W. 29 St., New York 1. This unit is designed for dentists and doctors, to secure intra-oral Kodachromes and for photographing in the specialties of dermatology, plastic surgery and opthalmology. The built-in light unit is independent of the flexible camera mount, and, to minimize patient discomfort, the two lamps in a fixed position glow at a low intensity except at the moment a picture is being taken. This unit has a retail price of $59.50.

Letters to the Editor

I have read with interest the article appearing in the March JOURNAL, entitled "Spontaneous Ignition of Decomposing Cellulose Nitrate Film."

There is no doubt, as the authors state, that deterioration of film caused mainly by faulty processing can be a source of spontaneous combustion, but this does not tell the entire story. Spontaneous fires can also start in cellulose nitrate film without the preliminary warnings detailed in the excellent photographs appearing in the article.

We recently had a fire which took place with comparatively new film in which the gelatin had been removed by our usual washing process and we know that this film was clean and free of any extraneous matter when it ignited.

My contention is that cellulose nitrate can contain higher degrees of nitration than is wanted for film and this higher nitration at times is one of the causes of spontaneous combustion, particularly with elevation of temperatures. I realize that this is an alarming statement, but it is borne out by my experience. The remedy is that the film should, therefore, be stored under proper conditions.

For one thing, film should not be stored in iron drums, as they are conductors of heat and rapidly transmit the heat from one drum to another in a vault filled with such drums.

The fundamental thing in designing vaults and containers, and in storing nitrate film, is insulation, not conductivity. Insulation is obtained by separating quanti-

ties of film one from the other with a nonconductor, such as asbestos, wood, cardboard, plastics and other insulating material. Conductivity is obtained by storing the film in metal cans, on metal shelves, and in metal containers, such as steel drums. In other words, film should be kept away from metal as far as is practical and surrounded only by nonconductors such as those enumerated.

If under these ideal conditions a film does ignite or explode, due to deterioration from one cause or another, the fire is then confined to a small area.

April 13, 1950 JOSEPH H. SPRAY

Re: Mr. Spray's letter above.

We do not doubt that, under certain unusual conditions, new film can ignite spontaneously. Spontaneous ignition is the result of two phenomena, heat generation and heat dissipation. Heat is usually generated by some exothermic chemical reaction and is dissipated by conduction, radiation, and connection to the surroundings. When the rate of heat generation exceeds that of heat dissipation, the temperature of the material rises until ignition occurs. We understand that in Mr. Spray's plant the emulsion was removed from cellulose nitrate base film by washing in a hot caustic soda bath. The washed film was then cut to lengths and packed. The soda-ash residue that remains along with the film may react with it to generate more heat than is usually the case. Also, because of higher temperatures which prevail in certain parts of the plant, heat may not be dissipated as rapidly as desired. Under such conditions, material may self-ignite when it would not do so in normal storage. The paper, "Spontaneous Ignition of Decomposing Cellulose Nitrate Film," was written with an eye toward the prevention of fire in libraries and film exchanges. We still believe that under conditions prevalent in such installations, new film will not self-ignite.

The correspondent's contention that excessive nitration may be a cause of spontaneous ignition is interesting and should not be dismissed without careful study. However, there is the belief that because of the modern quality control methods used in the manufacture of nitrate film a uniform product results. Besides, if variation in the degree of nitration does exist, it has not been proven that the autogeneous ignition temperature will be affected. These two factors would have to be studied to confirm or deny the correspondent's hypothesis. We do know that Bureau of Standards investigators were unable to cause the spontaneous ignition of new film at ambient temperatures of up to 120° F.

We wholeheartedly agree with Mr. Spray that all nitrate film should be stored in insulated facilities under controlled temperature conditions. Engineers of the Interagency Committee for Nitrate Film Vault Tests have devised insulated racks which can, without the aid of sprinklers, contain a film fire to the reel in which it originated. Organizations storing quantities of nitrate film should consider, as a long-range project, the equipping of their facilities with this type of rack. Such a program may take years to execute, however, and will not reduce the danger of film fires in the near future. For that reason we recommend that procedure as outlined in the paper as being the only practical first aid solution to the problem for the immediate future.

June 12, 1950 JAMES W. CUMMINGS

Employment Service

POSITION AVAILABLE

Wanted: Individual who has had practical paid experience in the audio-visual field; must have knowledge of film storage procedures, circulating and maintenance of film, evaluation and catalog preparation. Must be able to meet the public and to supervise. Write: R. E. Herold, 5069 Montezuma St., Los Angeles 42, Calif.

POSITIONS WANTED

Cameraman - Director: Thorough knowledge of script-to-screen technique. Capable of own script preparation and production; 6 yr experience free-lance cameraman and producer; adept with all types 16-mm photographic and editing equipment. Wish permanent position with 16-mm industrial or TV producer; age 27, single, free to travel, details readily supplied. Robert Deming, 343 S. 13 East, Salt Lake City, Utah.

With 35-Mm Production Unit: Young veteran desires to learn motion picture production. Will work in any capacity. Single, 23, with 8 yr theater experience, all phases; mgr small house 3 yr; 2 yr A.M.P.S. projectionist supervisor; grad. AAF Photo School and Motion Picture Inst. production course. Have private library of over 200 film books; serious student of films since 15. Currently employed; detailed letter and refs readily supplied; salary no object. John P. Lowe, 265 State St., Northampton, Mass.

Producer-Director-Editor: 10 yr with major film producers. Thorough knowledge and experience script-to-screen production technique: directing, photography, editing, laboratory problems, sound recording, 35- and 16-mm, b & w. Specialist in research and production of educational and documentary films; small budget commercial and TV films. Long experience in newsreels. Desire greater production possibilities, go anywhere. Member SMPTE, top refs. E. J. Mauthner, P. O. Box 231, Cathedral Sta., New York 25.

Mechanical-Electronic Engineer: B.S. degree in Mechanical Engineering; extensive design, mfg. experience, standard and drive-in theater picture and sound equipment; experience as engineering assistant to top management exec. corp. in radio TV. Write A. Kent Boyd, 3308 Liberty St., Austin, Texas.

In **Manufacturing:** Broad experience in developing, improving and producing of home movie cameras and projectors. Good technical background. Desire position with mfr. Earle F. Orr, 345 Fellsway West, Medford, Mass.

On-the-Job G.I. Bill Training: Ambitious young man to be member of camera crew; grad. U.S. Army Signal Corps Schl.; experienced with Cine Spec., 70DA, Eyemo, Wall and Mitchell cameras; studied editing, art directing and cinematic effects at U.S.C.; married, non-drinker, serious; man for small studio TV work. P.O. Box 524, Alhambra, Calif.

TV and Motion Picture Production Supervisor: 18 yr of unusually complete and varied experience in production of films for theatrical, educational, commercial and TV fields. Heavy technical background in animation, special effects, optical printing, stop-motion, as well as live action. Installed five animation and special effects departments now in operation. Chief cinematographer on U.S. Govt. training films. Experience covers Technicolor, b & w, 35- and 16-mm. Good laboratory background. Would like executive liaison position to supervise production, where creative ability and knowledge of lesser-known techniques could be utilized. Will travel anywhere within U.S. Member of SMPTE for 15 yr. More detailed résumé and references supplied on request. Ernest M. Pittaro, 1930 Grand Concourse, Bronx 57, New York.

Papers Presented at the Chicago Convention, April 24-28

LISTED BY SESSIONS

MONDAY NOON

Spyros P. Skouras, 20th Century-Fox Film Corp., New York, N.Y., "Television and the Motion Picture Theater."

MONDAY AFTERNOON

Edwin C. Fritts, Camera Works, Eastman Kodak Co., Rochester, N.Y., "A Heavy Duty 16-Mm Projector."

George J. Koch, Camera Works, Eastman Kodak Co., Rochester, N.Y., "Interference Mirrors for Arc Projection."

James A. Moses, Army Pictorial Service Division, Washington, D.C., "Armed Forces 16-Mm Film Program."

Frank P. Herrnfeld, Ansco, Hollywood, Calif., "Flutter Measuring Set."

Loren L. Ryder, Paramount Pictures, Hollywood, Calif., "Motion Picture Studio Use of Magnetic Recording."

Walter T. Selsted, Ampex Electric Corp., San Carlos, Calif., "Lip-Synchronous Recording on Standard Unperforated Magnetic Tape."

M. Rettinger, RCA Victor Division, Hollywood, Calif., "A Magnetic Record-Reproduce Head."

Edward P. Kennedy, Squier Signal Laboratory, Ft. Monmouth, N.J., "New Sound Film Stabilizing System for 16-Mm Recording and Reproduction."

John J. McCormick, Navy Motion Picture Exchange, Brooklyn, N.Y., "U.S. Navy 16-Mm Review Room Characteristics."

MONDAY EVENING

Frank H. McIntosh, Consulting Engineer, Washington, D.C., "The Properties and Characteristics of Color Television Systems Proposed to F.C.C."

John R. Howland, Zenith Radio Corp., Chicago, Ill., "Phonevision Progress."

TUESDAY MORNING

W. R. Fraser and G. J. Badgley, Naval Photographic Center, Anacostia, D.C., "Motion Picture Color Photography of Color TV Images."

Arthur B. Bronwell, Northwestern University, Evanston, Ill., "Critical Evaluation of Color Television."

Constantin S. Szegho, The Rauland Corp., Chicago, Ill., "Color Cathode Ray Tube with 3 Phosphor Bands."

F. N. Gillette and J. S. Ewing, The Hertner Electric Co., Cleveland, Ohio, "Component Arrangement for a Versatile Television Receiver."

France B. Berger, General Precision Laboratory, Inc., Pleasantville, N.Y., "Characteristics of Motion Picture and Television Projection Screens."

E. Arthur Hungerford, Jr., U. S. Navy Special Devices Center, Port Washington, N.Y., "Television As a Means of Mass Instruction in the Armed Forces."

TUESDAY AFTERNOON

R. L. Garman and R. W. Lee, General Precision Laboratory, Inc., Pleasantville, N.Y., "Television Pick-Up Tubes and Techniques Used in Studio Film Chain Cameras."

Richard S. O'Brien, Columbia Broadcasting System, Inc., New York, N.Y., "CBS Television Staging and Lighting Practices."

D. C. G. Hare, D. C. G. Hare Co., New Canaan, Conn., and W. D. Fling, Fairchild Recording Equipment Co., Whitestone, N.Y., "Picture-Synchronous Magnetic Tape Recording."

J. S. Hall, A. Mayer and G. Maslach, General Precision Laboratory, Inc., Pleasantville, N.Y., "16-Mm Rapid Film Processor."

R. L. Garman and Blair Foulds, General Precision Laboratory, Inc., Pleasantville, N.Y., "Some Commercial Aspects of A New 16-Mm Intermediate Film Television System."

Wayne R. Johnson, Earle C. Anthony, Inc., KFI-TV, Los Angeles, Calif., "Progress Report on An Experimental Electronic Background Projector for Television."

Rudy Bretz, Dramatic Workshop and Technical Institute, New York, N.Y., "Television Special Effects."

TUESDAY EVENING

Carl Meyers and F. R. McNicol, WGN-TV, Chicago, Ill., hosts for a conducted tour of WGN-TV's new studios in process of completion.

Ted Lawrence, CBS-TV, New York, N.Y., Chairman for a discussion period on television studio lighting, with brief discussions by: Carl Meyers, F. R. McNicol and George Petterson, WGN-TV; and Frank Koerner, WENR-TV, Chicago, Ill.

Oscar Holmes, Holmes Projector Co., Chicago, Ill., Demonstration of New Direct Film and Background Projector.

WEDNESDAY MORNING

M. Sultanoff, Terminal Ballistic Laboratory, Aberdeen Proving Ground, Md., "A 100,000,000 Frame Per Second Camera."

Elinor Porter Muhl, Earl H. Hinz and C. A. Main, Department of Aeronautical Engineering, University of Minnesota, Minneapolis, Minn., "High Speed Photography of Reflection—Lighted Objects in Transonic Wind Tunnel Testing."

C. D. Miller, Battelle Memorial Institute, Columbus, Ohio, "Phenomena Involved in Engine Knock Photographed at 40,000 to 200,000 Frames Per Second."

WEDNESDAY AFTERNOON

Brian O'Brien, Gordon G. Milne and William Covell, Institute of Optics, University of Rochester, Rochester, N.Y., "High Speed Image Dissection Camera Type II."

H. N. Olsen and W. S. Huxford, Department of Physics, Northwestern University, Evanston, Ill., "Electrical and Radiation Characteristics of Flash Lamps."

Frederick E. Barstow, Edgerton, Germeshausen and Grier, Inc., Boston, Mass., "Infra-Red Photography with Electric Flash."

Paul M. Fye, Naval Ordnance Laboratory, White Oak, Md., "The High-Speed Photography of Underwater Explosions."

John Nash Ott, Jr., John Ott Pictures, Inc., Winnetka, Ill., "Time Lapse Motion Picture Photography."

THURSDAY AFTERNOON

H. J. Benham, Brenkert Light Projection Co., Detroit, Mich., and R. H. Heacock, RCA Victor Division, Camden, N.J., "A New Deluxe 35-Mm Motion Picture Projector Mechanism."

Arthur J. Hatch, The Strong Electric Corp., Toledo, Ohio, "The Differential Carbon Feed System for Projection Arc Lamps."

Herbert Griffin, International Projector Corp., Bloomfield, N.J., "A New Heavy Duty Professional Theater Projector."

Henry J. Hood, Eastman Kodak, Co., Rochester, N.Y., "Report of SMPTE 16-Mm and 8-Mm Motion Picture Committee."

J. W. McNair, American Standards Association, New York, N.Y., "Standardization on Photography and Cinematography."

Tom H. Miller, Training, Dept., Eastman Kodak Co., Rochester, N.Y., "Stop and Go Signs in Color Photography."

THURSDAY EVENING

W. W. Lozier, National Carbon, Fostoria, Ohio, "Report of SMPTE Screen Brightness Committee."

Herman H. Duerr, Ansco, Binghamton, N.Y., "Report of SMPTE Color Committee."

W. T. Hanson, Jr., Research Laboratory, Eastman Kodak Co., Rochester, N.Y., "A Color Negative and A Color Positive Film for Motion Picture Use."

Edgar Gretener, Edgar Gretener, A. G., Zurich, Switzerland, "Physical Principles, Design and Performance of the Ventarc High-Intensity Projection Lamps."

FRIDAY MORNING

M. G. Townsley, Bell & Howell Co., Chicago, Ill., and P. L. Pryor, Air Materiel Command, Wright Field, Dayton, Ohio, "A Large T-Stop Calibrating Unit."

E. E. Strauss, J. G. Zuber and M. G. Townsley, Bell & Howell Co., Chicago, Ill. "A New Portable 35-Mm Motion Picture Camera."

William P. Bielicke, George W. Colburn Laboratory, Chicago, Ill., "Conditions and Progress in the German Motion Picture Industry."

H. Goldin, Gaumont-Kalee, Ltd., Toronto, Canada, "The Acoustic Design of New Odoen Theatres."

May Benson, MacKay Research Laboratory, Chicago, Ill., "Photo-Sensitive Devices and Excitation Sources."

George W. Colburn, George W. Colburn Laboratory, Chicago, Ill., "Double and Single Film 16-Mm Projectors with Variable Picture/Sound Synchronization for Laboratory and TV Studio Use."

FRIDAY AFTERNOON

John G. Stott, Du Art Film Laboratories, New York, N.Y., "Report of SMPTE Laboratory Practice Committee."

E. K. Carver, Eastman Kodak Co., Rochester, N.Y., "Report of SMPTE Film Dimensions Committee."

H. W. Cleveland, Research Laboratory, Eastman Kodak Co., Rochester, N.Y., "A Method of Measuring Electrification of Motion Picture Film Applied to Cleaning Methods."

Thomas T. Hill, The Edwal Laboratories, Inc., Ringwood, Ill., "Securing Optimum Results in Fixing and Washing Photographic Materials."

R. Paul Ireland, EDL Co., Chicago, Ill., "A Method of Tone Reproduction Control in Reversal Processing."

C. A. Horton, Research Laboratory, Eastman Kodak Co., Rochester, N.Y., "Printer Control in Color Printing."

John P. Kiel, Producers Service Company, Burbank, Calif., "A 35-Mm Process Camera."

Don Norwood, Pasadena, Calif., "Light Measurement for Exposure Control."

Members, Members, Members

Who among your friends and associates should become members of the Society? All to whom technology of motion pictures and television is important.

When this issue went to press there were nearly 3400 members on the rolls and on page 763 you will find the names of 38 who joined since the 1950 *Directory* was published in May. Names of the most recent new members will appear in each future issue. You can help this list grow by enrolling each likely candidate whom you know.

Write to Society Headquarters for membership brochures and application forms. They will be sent by return mail.

L. E. Jones, *Chairman*
Membership and Subscription Committee

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